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Effect of Land Disposal Applications of Municipal Wastes on Crop Yields and Heavy Metal Uptake

National Fertilizer Development Center, Muscle Shoals, Ala.

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16. ABSTRACT

This report provides the cumulative data acquired from 1969 through 1975 from field and greenhouse investigations pertaining to the effects on selected soils and plants from municipal compost and sewage sludge applications. Multiple applications of composted municipal refuse resulted in satisfactory crop growth with only moderate increase of some heavy metals in plant tissue. In contrast, lower rates of several domestic sewages resulted in significant uptake of certain metals, especially in more sensitive species, such as leafy vegetables and string beans. Plant availability of metals derived from sewage seems to be related to product matrix rather than to total metal content. Little downward movement of heavy meta's was observed under conditions of heavy leaching in the greenhouse or natural rainfall outdoors.

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EFFECT OF LAND DISPOSAL APPLICATIONS OF MUNICIPAL WASTES ON CROP YIELDS AND HEAVY METAL UPTAKE

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

In the late 1960's, predecessors of the Environmental Protection Agency initiated projects to investigate and demonstrate the use of composting as a methodology for managing municipal solid waste in the United States. For composting to be successful in the United States, markets would have to be established for the compost products, or at least acceptable disposal techniques for the compost product would be required. A logical choice was the application of composted waste materials to crop lands as an organic soil supplement, to other lands for reclamation and/or to lands merely as a disposal site.

During 1969, field and greenhouse experiments were begun to investigate the effects, on selected soils and plants, of composted waste materials when applied to the lands. Because such studies require long periods to determine effects, they were continued after the termination of the Johnson City Composting project. This report provides the cumulative results of the field and greenhouse research conducted from 1969 through 1975. It provides basic data on the effects of organic waste materials when applied to selected soils and crops and will add to the knowledge required to determine the environmental consequences of using the land as a receptor of waste materials.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report presents the cumulative data acquired from 1969 through 1975 from field and greenhouse investigations pertaining to application of municipal compost and sewage sludge on cropland. Multiple applications of composted garbage refuse totaling 900 metric tons per hectare have resulted in satisfactory crop growth with only a moderate increase of some heavy metals in plant tissue. In contrast lower rates of several domestic sewages resulted in significant uptake of certain metals, especially in more sensitive species, such as leafy vegetables and string beans. Plant availability of metals derived from sewage seems to be related to product matrix rather than to total metal content. Very little downward movement of heavy metals was observed under conditions of heavy leaching in the greenhouse or natural rainfall outdoors. These results suggest that ground water contamination from heavy municipal waste application is unlikely except in very acid soils where mobility would be greater.

This report was submitted in fulfillment of Contract No. EPA-IAG-D4-0415 by the Soils and Fertilizer Research Branch of the Tennessee Valley Authority under the partial sponsorship of the Environmental Protection Agency. Work was completed as of December 1975.

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SECTION I

SUMMARY

Much attention is being directed toward land application as a means of municipal waste disposal. However, before this practice can be recommended more research is necessary with regard to waste characterization, pathogenicity, site selection, and long-term effects on crop production and food chain pollution. The present investigation was undertaken with the principal objective to study heavy metal implications in soils and plants. Due to the limited resources directed to this project, investigation of other factors was not feasible.

Since many sewage sludges contain appreciable quantities of zinc (Zn) as well as potentially toxic heavy metals, including cadmium (Cd), nickel (Ni), and lead (Pb), recent investigations have been initiated to study the reactions of these metals in soils and factors which affect their uptake by crop plants.

Field studies were begun in 1968 to evaluate composted municipal waste as a soil amendment (Section V.A.). Yield responses were observed with annual compost applications of rates up to 143 and 80 metric tons/hectare (ha) on sorghum and bermudagrass, respectively. However, the highest yields of either crop attained with compost were surpassed by application of fertilizer nitrogen (N) at the rate of 180 kg/ha, together with adequate phosphorus (P) and potassium (K). Aside from enhancing the fertility of the soil, compost applications increased moisture-holding capacity and decreased the bulk density and compression strength of the soil. These effects, however, did not persist beyond 3 years. Although these experiments indicated that large tonnages of compost can be applied to grass- or cropland, the economic return is minimal. Of further concern was the observation that compost-treated crops showed elevated levels of Zn and to a lesser extent other heavy metals, although these were largely derived from the sewage sludge added to the composted garbage.

The next phase of this investigation was to compare the immediate and residual availability of Zn to vegetable crops when applied in the form of $ZnSO_4$ or as a constituent of municipal garbage compost or sewage sludge (Section V.B.). When $ZnSO_4$ and compost or sewage sludge were applied at rates resulting in comparable applications of Zn, availability of Zn to both sweet corn and string beans was considerably greater from $ZnSO_4$ over a 4-year period. In general string beans were less tolerant of high Zn treatments even when applied as sewage sludge. Of the other heavy metals routinely monitored in these crops, only Cd levels exceeded check values in the plant leaves; edible plant parts were relatively unaffected. Bean pods only appeared to accumulate Ni from sewage sludge, reaching levels two to four times those from nontreated plots. Although there was no indication

that the elevated Cd or Ni levels were phytotoxic, the consequence of animal or human consumption was not determined.

Other vegetable species were grown on soil amended with anaerobically digested sewage sludge obtained from two municipalities in north Alabama (Section V.C.). Increased yields of tomatoes and squash were obtained in response to application of both waste materials; other species were unaffected. Leafy vegetables, such as lettuce and spinach, were accumulators of Zn, Cd, and copper (Cu). Radish and turnip roots contained somewhat lower levels of Zn and Cd, while vegetables consumed as fruits or seed pods were relatively low in heavy metal content. Despite the differences in metal content between the two sewages, plant uptake was not always related to content in the material. This suggests that the chemical form may also be important in evaluating sludges for use on agricultural land.

Pot experiments conducted in the greenhouse to study phytotoxic levels of chromium (Cr), Cd, and Zn indicated that inorganic forms of these metals are taken up by plants in greater quantities than from organic wastes (Section VI). Whereas Zn concentrations in corn increased with rate of Zn applied as $ZnSO_4$ or organic waste, concentrations of Cr seldom exceeded check values in the plant foliage, even though growth was depressed. Apparently, Cr is effectively excluded by plants with very high soil concentrations, resulting in sufficient root damage to limit growth. Cadmium was readily accumulated in fescue, but growth was not depressed until concentrations exceeded approximately 100 parts per million (ppm).

Abatement of Cu, Pb, and Ni in mustard was not accomplished by liming the soil from pH 5.0 to 7.0. However, concentrations of Zn decreased significantly over this range and Cd decreased slightly from pH 5.0 to 6.0. Other studies are needed to evaluate liming as a means of heavy metal pollution abatement.

Investigations of heavy metal movement in soil profiles from municipal waste applications have been conducted under simulated and natural rainfall conditions (Section VII). Results show that mobility of heavy metals is slightly greater from inorganic than from organic forms but is minimal even under severe leaching situations. Based on these findings, it is unlikely that disposal rates of municipal wastes applied to cropland pose a threat to our water supply. However, the consequence of prolonged use on cropland and subsequent soil management practices is obscure.

SECTION II

CONCLUSIONS

1. Data herein show that large tonnages of municipal compost can be applied on grassland or cropland with occasional positive yield responses. However, the value is low when compared with the cost of chemical fertilizer needed to produce equivalent yields. Thus, composting of organic wastes should be considered largely as a useful alternative method of disposal, rather than as a substitute for inorganic fertilizer.

2. Application of rather high rates of sewage sludge (> 50 metric tons/ha) may increase vegetable production of some species, but this apparent benefit may be accompanied by increased levels of one or more heavy metals. Since certain vegetable species are sensitive to heavy metal accumulation, toxicity may cause decreased yields and higher levels of heavy metals in the plants. Although concentrations are generally higher in vegetative tissue, in some instances the reproductive plant parts may be sinks for certain metals. The significance of Cd and Ni concentrations, ranging from two to five times those in vegetation from unamended plots, is yet to be determined with regard to food chain implications.

3. Total heavy metal content of a sewage sludge does not necessarily reflect plant availability. Transformations may occur in soils which increase or decrease availability in these waste products. The organic matter content and composition of the waste material likely influence availability depending upon the stability of the metal complexes formed and the subsequent resistance to decomposition. Apparently the pH value of the sludge per se is not a reliable indicator of plant availability. However, under very acid soil conditions (< pH 5.0), sewage sludge high in Zn content may be toxic to plants. Inorganic sources of Zn initially are more toxic than organic wastes at equivalent rates of application and constant soil pH. The consequence of multiple applications of sludge is unknown. Although heavy metals accumulate with repeated treatment, the organic matrix seems to be protective.

4. Results show that movement of heavy metals in soil is greater from inorganic than from complexed sources found in sewage sludge under severe leaching conditions; other studies indicate little difference in mobility with normal rainfall and minimal supplemental irrigation.

5. Although moderate rates of "low risk" sludge pose little hazard to crops, at least during the first year after application, continued use of municipal wastes may ultimately result in heavy metal overloading, especially in some light-textured soils.

SECTION III

RECOMMENDATIONS

1. Municipal waste materials should be carefully characterized with respect to total elemental composition and solubility prior to land disposal. Reactions of organic wastes in soils need further study. Although results suggest that most heavy metals contained in wastes are rather immobile in soils, long-term studies must be forthcoming before the consequence of repeated applications of heavy rates is completely understood.

2. Although a number of crop species have been identified as excluders or accumulators of certain heavy metals, further delineation is necessary. Routine leaf analysis is not sufficient, since certain edible plant parts other than leaves may be sinks for particular heavy metals.

3. More greenhouse and laboratory work is needed to correlate heavy metal uptake with soil extraction procedures. Existing extractants used for micronutrients may not be suitable for all heavy metals.

4. There has been little evidence in these studies of heavy metal conversion to more available forms. Organic matter content should be monitored for several more years from plots receiving both single and multiple applications of municipal wastes. Furthermore, soil samples should be extracted during this period to determine whether metal availability to plants is changing. The effect of soil acidification and heating on solubilization and mobilization of metals is being investigated.

5. Guidelines must be established regarding tolerable levels of heavy metals in food chain components before the significance of elevated levels in crops can be evaluated. It also must be recognized that surface contamination is a contributing factor.

SECTION IV

INTRODUCTION

Prior to about 1955, applying manures and sludges on crop and recreational land was aimed at correcting nutritional deficiencies or adverse physical conditions rather than disposal of an overabundant waste product. As a result, much lower rates were applied. Also, content of potentially hazardous heavy metals was lower in manures because it included excessive antibiotic doses of Cu and Zn (4).

Large quantities of municipal garbage and sewage sludge generated by modern society are creating a serious problem of disposal (1). Land filling appears to be the least costly acceptable method of disposal in the United States. Incineration has some potential but may be subject to many constraints. The value of municipal refuse and sewage as sources of plant nutrients has long been recognized. Unfavorable economics has restricted the use of these materials, although several municipal waste products have been marketed successfully for many years, primarily for use on ornamentals and turf. Rising costs of commercial fertilizers have stimulated interest in use of sewage sludge not only for recreational areas and home grounds but also for crop production.

Among the problems associated with land application of "disposal rates" (> 25 metric tons/ha) of sludges for crop production are (i) the potential toxicity to plants from contained heavy metals, (ii) entrance of heavy metal contaminated plant material into the food chain directly or through animals, and (iii) possible pollution of ground waters as a result of heavy metal migration. This report deals with the yield response and heavy metal accumulation by several plant species grown on soil amended with varying types and rates of municipal wastes. Special emphasis was placed on studies of cumulative and residual availability of Cd, Zn, Ni, Pb, and Cu to vegetable crops grown in the field. Also, mobility of these metals in soil was investigated in the greenhouse and in a rhizotron-lysimeter under leaching conditions and natural rainfall to determine whether ground water contamination would follow heavy applications of municipal wastes.

SECTION V

FIELD STUDIES

A. RESPONSE OF FORAGE SORGHUM AND COMMON BERMUDAGRASS TO MUNICIPAL WASTE COMPOST

Experiments were begun in 1969 to evaluate the effects of composted municipal waste as a soil amendment (11, 17, 18). The primary objectives were to measure crop response to applied compost and to determine the application rate above which compost might be detrimental to crop production.

The compost was produced at Johnson City, Tennessee, in an experimental composting plant operated jointly by the Tennessee Valley Authority, the Environmental Protection Agency (at that time, the U.S. Public Health Service), and Johnson City (9).

The raw material was municipal waste or garbage containing food wastes, paper and cardboard, plastic, cloth, metal, glass, and other items found in city waste. The garbage was fortified with sewage sludge in amounts as great as 20% on a dry-weight basis. Initially, only coarse grinding was practiced and the compost was fluffy, poorly composted, and contained many identifiable objects. As technology improved, a finely ground, well composted product with a satisfactory physical appearance was produced. Chemical analyses of the lots of compost used are shown in Table 1.

In the first experiment at Muscle Shoals, Alabama, forage sorghum (Sorghum bicolor L. Moench x Sorghum sudanense P. Stapf., cv., 'Funk's 101F' and later 'Funk's 102F') was the test crop. Thirteen treatments comparing combinations of fall and spring applications with and without supplemental N fertilizer were compared on a Sango silt loam soil. All high rates were applied in split fall and spring application. Composts at total application rates ranging from 23 to 326 metric tons/ha on a dry-weight basis were applied over a 2-year period. All plots were uniformly fertilized with 28 kg of P and 112 kg of K/ha at the beginning of the experiment. All treatments were replicated four times in 3.7- by 9.2-meter plots.

Two cuttings of sorghum forage were removed each year from 1969 through 1971; in subsequent years the sorghum was cut only once. Forage samples were analyzed for several macro- and micronutrients.

TABLE 1. CHEMICAL ANALYSES OF COMPOSTS USED (%, DRY WEIGHT BASIS).

Application time	N	P	K	C	Ca	Na	Mg	S	Zn
Fall 1968	1.2	0.2	0.8	34.2	3.6	0.5	0.5	0.4	0.1
Spring 1969	1.3	0.4	1.0	26.8	6.4	0.8	0.9	0.4	0.1
Fall 1969 and spring 1970	1.3	0.3	1.0	27.3	4.6	0.7	0.6	0.5	0.1

In a second experiment, common bermudagrass (Cynodon dactylon L.) was topdressed with compost in November 1968 at rates of 0, 9, 18, and 27 metric tons/ha. In the winter of 1969-1970, compost was applied to the same plots at triple the 1968 rate. Nitrogen rates of 0 and 180 kg/ha were superimposed on plots at each compost rate. One-half of the N was applied in April and the other half after the second harvest. The grass was cut four times.

1. Results on Sorghum

At the low rates where fall versus spring applications were compared, no differences due to application schedule were noted. Yield responses for the two cropping seasons for which compost was applied are shown in Figure 1. Total yield levels were higher in 1969 because of more favorable midsummer rainfall. Response was curvilinear, with the yield still increasing at the highest application rate. It required an application of 91 metric tons/ha of compost to produce as much forage as 90 kg of N/ha from ammonium nitrate (NH_4NO_3), but none of the compost rates produced as much forage as 180 kg of N/ha. Nitrogen plus compost produced higher yields than either applied alone.

Compost used for the 1969 crop year was coarse and fluffy. The fall plowdown application caused no problems but the spring application, incorporated by disking, made the preparation of a fine, firm seedbed impossible at application rates of 35 metric tons/ha or above. This resulted in poor germination and uneven stands, a problem not encountered in subsequent years with finely ground compost.

While yields were lower in 1970, the response to compost was greater, as shown by convergence of the 1969 and 1970 yield curves at increasing rates. This may have been partly due to the residual effect from compost applied for the 1969 season, but it seems likely that better soil moisture relationships resulting from the physical effects of high compost application were also important. As in 1969, effects of compost and N were additive.

Sorghum was grown for 5 more years to measure residual response to the 1969 and 1970 compost applications. In 1971 the residual response was similar to the 1969 and 1970 responses but by 1974 residual effects had disappeared. Data for the 1971-1974 period are shown in Figure 2. The area was fertilized uniformly each year with N and K each at 112 kg/ha. The yield level was increased significantly by fertilization but no residual compost response could be detected in 1974 and 1975.

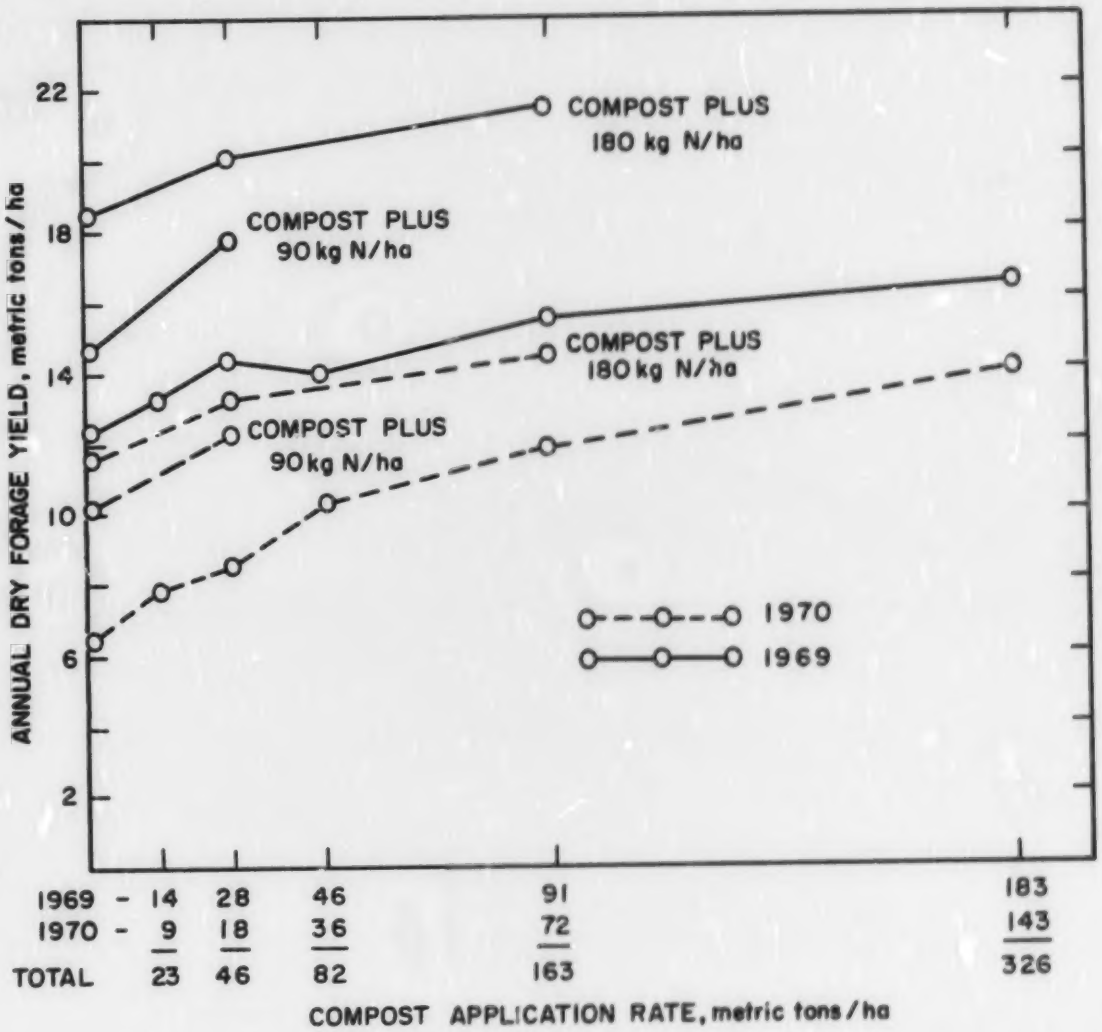

Figure 1. Effects of compost application on forage sorghum yield.

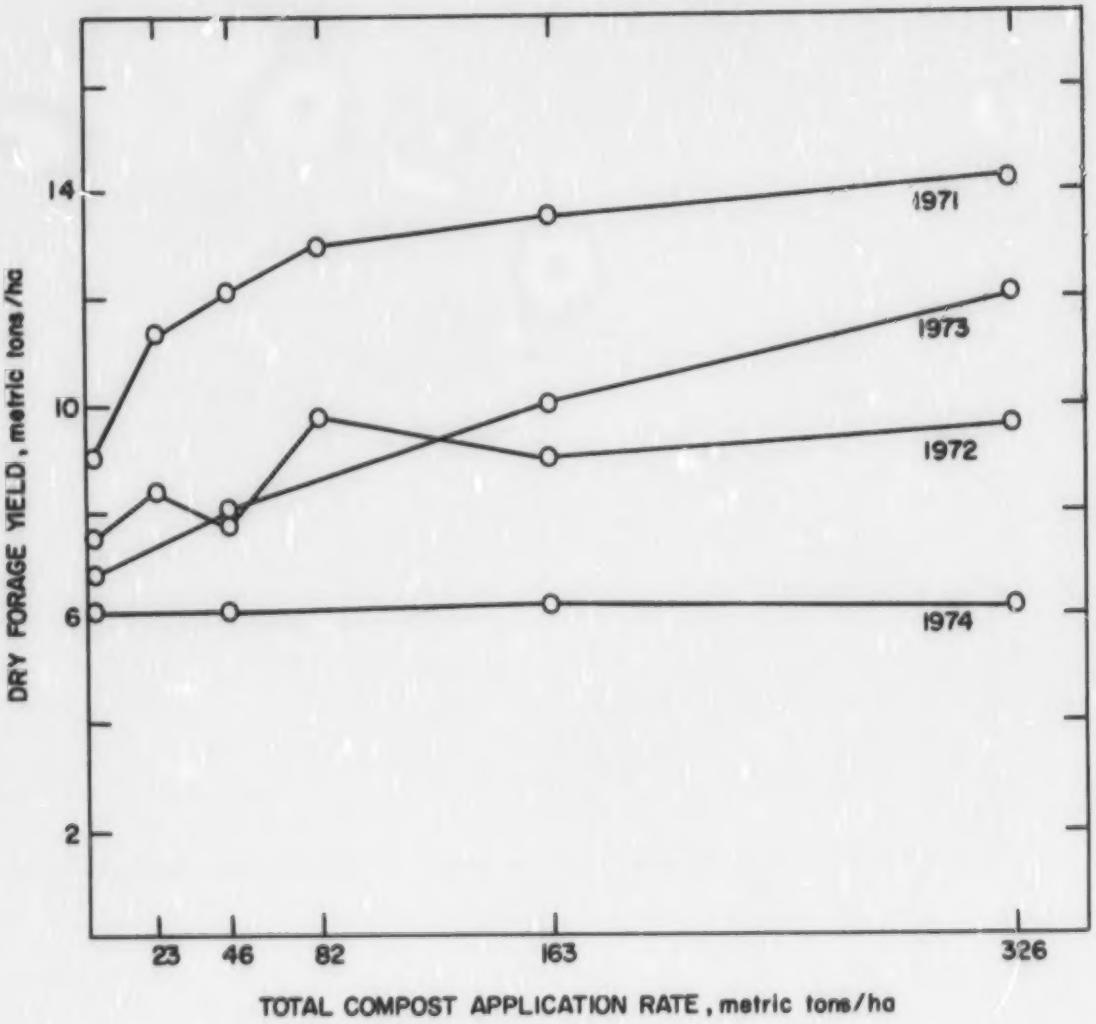

Figure 2. Residual effects of compost application on forage sorghum yield.

The contribution of compost to N in the crop is shown in Table 2. Significant amounts of N were supplied to the crop over a 6-year period totaling almost 400 kg/ha from the heaviest compost application. Although it is recognized that organic N must undergo conversion to NH_4^+ or NO_3^- before it is available to plants, this aspect was not pursued. The sorghum forage was analyzed for a wide range of elements, but aside from N, only K, sodium (Na), Zn, and Cu concentrations were modified by compost application (Table 3). These increases show that the effect lasted throughout the residual harvest period. Concentrations of Zn and Cu were still 50% higher in 1975 in forage from high compost plots, even though the soil pH (Table 4) was in the range where these elements are normally much less available. This emphasizes the potential for persistence of some heavy metals in the soil-plant system.

Table 4 shows chemical effects on soil from compost after 2 application years and also after 3 years of residual cropping. Organic matter content was more than doubled after 2 years of application, but the increases were largely dissipated after only 3 residual years, indicating that little compost was converted to stable organic matter fractions. Soil pH was increased by more than one unit at the highest application rate, apparently a stable effect. The pH effect was attributed largely to the high calcium (Ca) content of the compost.

Levels of several extractable nutrients are also shown. The added K was presumably removed in the sorghum crops, while the additions of Ca and magnesium (Mg) were fairly stable because of low crop uptake. Soil Zn values were increased significantly by the compost, presumably by the sewage sludge fraction. Unfortunately, Cd was not being monitored during this phase of the investigation. Changes in soil P could not be readily characterized because of the high level already present in the soil.

Reductions in soil bulk density and compression strength (an indication of reduced power requirements for tillage) were significant in 1970, but there was little residual effect by 1973 (Table 5). Compost had a favorable effect on soil moisture holding capacity, as indicated by the soil moisture content at the 1970 sampling. This effect was seen during any period of prolonged moisture stress as sorghum growing on high compost plots always showed less leaf curling.

TABLE 2. NITROGEN CONTRIBUTION FROM COMPOST.

Dry compost rate, metric tons/ha			Nitrogen uptake above no compost value, kg/ha					
1969	1970	Total	1969	1970	1971	1972	1973	1974
14	9	23	5	17	25	16	18	- 8
28	18	46	24	19	42	8	18	- 3
46	36	82	23	46	47	51	9	- 4
91	72	163	39	56	72	27	23	16
183	143	326	68	113	105	43	35	27

TABLE 3. COMPOST EFFECTS ON NUTRIENT CONCENTRATIONS IN SORGHUM FORAGE.

Compost rate, metric tons/ha								
1969	1970	Total	1970	1971	1972	1973	1974	1975
			K, %					
0	0	0	1.7	1.1	1.1	1.0	0.9	
28	18	46	1.7	1.3	1.3	1.1	1.1	
46	36	82	1.8	1.5	2.1	1.2	1.3	
91	72	163	2.0	1.7	1.7	1.3	1.3	
183	143	326	2.1	2.0	2.0	1.5	1.5	
			Na, ppm					
0	0	0	46	82	36	75	80	
28	18	46	39	86	40	75	112	
46	36	82	38	96	50	100	93	
91	72	163	64	104	46	100	91	
183	143	326	54	108	36	125	118	
			Zn, ppm					
0	0	0	32	22	19	20	28	24
28	18	46	34	32	23	26	30	29
46	36	82	41	40	45	27	34	34
91	72	163	50	51	36	27	38	33
183	143	326	57	68	40	32	48	37
			Cu, ppm					
0	0	0	4.0	3.5	3.4	3.0	5.4	3.8
28	18	46	4.4	4.5	3.6	3.0	6.2	4.0
46	36	82	4.4	5.0	5.8	3.0	6.4	4.0
91	72	163	5.1	6.8	4.8	4.0	6.7	4.2
183	143	326	5.6	7.0	5.1	3.0	7.8	5.1

TABLE 4. COMPOST EFFECTS ON SOME CHEMICAL CHARACTERISTICS OF SOIL.

Total compost application metric tons/ha	Organic matter %		pH		Extractable nutrients, kg/ha							
					K		Ca		Mg		Zn	
	1970	1973	1970	1973	1970	1973	1970	1973	1970	1973	1970	1973
0	1.6	1.2	5.4	5.6	193	109	1653	2688	181	171	7	27
46	1.8	1.4	6.2	6.4	197	100	2340	3420	199	214	29	45
163	2.7	1.6	6.6	6.8	278	120	3349	4154	224	233	91	71
326	4.2	2.0	6.8	6.9	332	108	3920	4764	234	255	490	118

TABLE 5. COMPOST EFFECTS ON SOME PHYSICAL CHARACTERISTICS OF SOIL.

Total compost application metric tons/ha	Soil moisture, %		Bulk density		Unconfined compression strength, kg/cm^2	
	1970	1973	1970	1973	1970	1973
0	12.4	10.4	1.37a*	1.50 n.s.	2.9a	2.5 n.s.
46	12.5	10.3	1.32a	1.45	2.9a	2.3
163	13.3	10.7	1.22b	1.44	2.4b	2.1
326	14.8	11.2	1.12c	1.43	1.5c	2.2

*Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

A summary of this research indicates the following:

1. Municipal waste compost can be applied at rates as high as 326 metric tons/ha over a 2-year period without any important detrimental effects on sorghum production or quality.

2. Yield increases were obtained with each increase in the rate of compost application.

3. Compost appears to be worth only a few dollars per ton if equated with the cost of enough commercial fertilizer to achieve similar yield increases.

4. Residual yield responses were obtained for 3 years after the last application.

5. Effects on soil organic matter and exchangeable K levels were largely dissipated 3 years after application but changes in pH and exchangeable Ca, Mg, and Zn persisted.

6. Bulk density and compression strength were reduced and soil moisture content was increased by compost applications, but these changes did not persist beyond 3 years.

2. Results on Bermudagrass

Common bermudagrass yields (Table 6) show that bermudagrass sod can accept heavy applications of surface-applied compost and show a slight yield response. Without added N the high compost rate produced significantly more forage than no compost in 1969, while all compost rates were better than no compost in 1970. As with sorghum, yield increases from compost do not pay the cost of compost production, transportation, and application.

It seems that the most critical consideration for compost being used on forage land is the absence of glass, metal, or other foreign material in particles big enough to be ingested by grazing animals or picked up in harvested hay. However, significant quantities of heavy metals derived from the wastes may also enter the food chain directly as a result of plant surface contamination and consumed waste material.

TABLE 6. COMMON BERMUDAGRASS YIELD, AS AFFECTED BY COMPOST AND N.

Compost rate metric tons/ha		N rate, kg/ha	Dry forage yield metric tons/ha*		
1969	1970		1969	1970	Avg.
0	0	0	6.5c	2.7d	4.5d
0	0	180	11.4a	5.6b	8.5b
9	27	0	7.4bc	4.0c	5.6c
9	27	180	11.2a	6.5ab	8.7b
18	54	0	7.6bc	6.3c	5.8c
18	54	180	12.5a	7.2a	9.9a
27	81	0	7.8b	4.7c	6.3c
27	81	180	11.9a	13.4a	9.2ab

*Values followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

B. RESPONSE OF SWEET CORN AND STRING BEANS TO ZINC AND OTHER HEAVY METALS CONTAINED IN MUNICIPAL WASTES

Because of higher levels of Zn found in forage sorghum as a result of compost application a comprehensive investigation was made of the availability of Zn contained in garbage compost and municipal sewage sludge relative to comparable rates of $ZnSO_4$ (7).

This experiment was conducted at Muscle Shoals, Alabama, in the fall of 1971 on Sango silt loam (pH 5.4). Treatments consisted of three rates each of dry garbage compost (56, 112, and 224 metric tons/ha), dry sewage sludge (50, 100, and 200 metric tons/ha), and $ZnSO_4$ all incorporated into the soil to provide the equivalent of 90, 180, and 360 kg of Zn/ha. The compost was from the experimental composting plant at Johnson City, Tennessee; sewage sludge was from the sewage treatment plant at Tuscumbia, Alabama. Elemental composition of these waste materials is shown in the Appendix. All treatments were replicated four times and original plot dimensions were 3.6 by 15.0 meters (plots were subdivided in the fall of 1972 to 3.6 by 7.5 meters). Sweet corn (Zea mays L., cv. 'Silver Queen') and string beans (Phaseolus vulgaris L., cv. 'White Half Runner') were selected as the test crops because of their contrasting response to high levels of available Zn. The entire area was sprinkler irrigated as needed to assure that moisture stress would not limit plant growth.

Before planting, NH_4NO_3 and KCl were applied uniformly to all plots and disked in at rates of 150 and 100 kg/ha of N and K, respectively. Sweet corn was planted in 90-cm rows (4 rows/plot) and later thinned to a population of 50,000 plants/ha. Corn was harvested when the grain was in the milk stage. After the corn crop was harvested, 50 kg/ha of N as NH_4NO_3 was disked into the soil prior to planting string beans. String beans including vines were harvested from the two center rows. Earlier results (J. J. Mortvedt and P. M. Giordano, unpublished TVA data) indicated that corn was much less sensitive to excessive Zn than field beans. Purves and Mackenzie (14) found beans to be highly susceptible to heavy compost applications as compared with several other garden vegetables.

Soil borings to a depth of 20 cm were taken from all plots shortly after planting corn each year. Ten-gram samples were extracted with 50 ml of 0.5 N HCl for 15 minutes and 20 ml of DTPA solution (10) for 2 hours at ambient room temperature, filtered, and analyzed for Zn, Cu, Pb, and Ni by atomic absorption spectroscopy and Cd and Cr using a flameless atomizer accessory. Sensitivity for Zn, Cd, Cr, Ni, and Pb was 0.01, 0.005, 0.07, 0.05, and 0.06 µg/ml, respectively. Background correction was made using a deuterium continuum source in the B channel.

At harvest the two center rows of each plot were cut, weighed, and both total dry matter production and yield of the edible portion were computed. Samples of plant material were washed in distilled water, oven-dried, ground in a Wiley mill equipped with stainless steel knives and screens, and dry ashed at 470C for 16 hours. The ash was digested in 5 ml of 6 N HCl for 10 minutes and brought to 25 ml. Solutions were then analyzed for Zn, Cu, Cd, Cr, Pb, and Ni as described previously. Significance of yield differences due to treatment were determined using the Duncan's Multiple Range Test. However, because of differences in elemental concentrations arising from growth dilution as well as treatment, statistics were misleading in interpreting concentration data.

Weed control was not a problem during the cropping season, since a preemergence herbicide was used. However, during late winter and early spring a multitude of winter annual weeds covered the sludge- and compost-treated plots. There was no evidence of inhibition of weed or crop seed from waste treatment. In fact, seedling stands often were superior, especially with compost, due likely to improved physical condition of the soil.

1. Results in 1972

The early liming effect from compost and sludge application is shown in Table 7. Soil pH increased from 4.9 in the check and $ZnSO_4$ plots to as high as 6.3 at the highest rate of compost. About 60% of the applied Zn was recovered from the soil with 0.5 N HCl regardless of soil pH value. Amounts of Cu, iron (Fe), manganese (Mn), and Pb extracted from the compost- and sludge-treated plots were much higher than from the check or $ZnSO_4$ plots; extractable Cr and Cd were slightly higher and Ni was similar to the check.

Dry forage yields increased significantly with applications of compost and sludge (Table 8). No toxicity was noted with any rate of $ZnSO_4$. Compared with the check plots, the concentrations of Zn in the corn forage were 2 to 3 times higher with compost and sludge and 5 to 10 times higher with $ZnSO_4$. This agrees with results reported by Terman, Soileau, and Allen (18) that Zn uptake increased with organic waste application. Concentrations of Zn in corn grain were much lower than in forage, even with $ZnSO_4$. Apparently most of the Zn accumulated in vegetative tissue and was not readily translocated to the grain. Unfortunately, it was beyond the scope of this project to study silage content and accumulation in animals consuming the silage.

Concentrations of Pb in forage and grain were not affected by organic wastes. Although the sludge contained about 1,600 ppm of Pb (132

TABLE 7. CONCENTRATIONS OF SEVERAL HEAVY METALS IN SANGO SILT LOAM EXTRACTED BY 0.5 N HCl (1972)

Treatment	Zn rate, ppm	Soil pH	Concentration in soil, ppm							
			Zn	Cu	Fe	Mn	Cr	Pb	Ni	Cd
Check	0	4.9	4	3	154	100	0.2	10	1.1	0.5
$ZnSO_4$	40	4.9	28	3	153	111	0.3	7	1.3	0.4
	80	4.9	51	2	161	103	0.4	7	1.9	0.5
	160	4.9	106	3	141	90	0.2	11	1.3	0.8
Compost	40	5.7	32	9	247	147	0.9	23	1.3	0.6
	80	5.7	47	15	285	191	1.5	41	2.1	1.0
	160	6.3	80	18	360	203	3.0	49	2.1	1.7
Sludge	40	5.3	29	10	258	222	1.2	28	1.8	2.5
	80	5.3	53	19	363	213	2.0	57	1.4	2.8
	160	5.6	93	27	513	229	5.3	79	2.1	2.9

TABLE 8. DRY FORAGE YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN CORN FORAGE AND GRAIN (1972).

Treatment	Zn rate, kg/ha	Dry forage yield, kg/ha	Concentration in corn forage (F) and grain (G), ppm							
			Zn		Pb		Ni		Cd	
			F	G	F	G	F	G	F	G
Check	0	3051a*	41	37	3.4	0.9	4.4	5.1	1.0	0.3
$ZnSO_4$	90	3493a	227	49	3.6	0.7	3.6	6.9	0.9	0.2
	180	4363b	314	57	1.8	0.7	3.1	6.9	0.7	0.2
	360	3230a	475	68	2.9	0.8	3.0	4.1	1.0	0.3
Compost	90	4958bc	77	45	2.3	0.4	3.8	4.1	2.3	0.7
	180	5503cd	98	43	2.0	0.8	2.4	4.6	3.3	0.9
	360	6039d	100	69	3.4	2.7	4.6	2.6	5.3	1.1
Sludge	90	5839cd	94	43	1.5	0.5	2.6	4.0	3.7	0.9
	180	5963d	95	49	1.1	0.6	4.5	4.5	3.5	1.0
	360	5945d	97	44	2.5	1.0	3.1	3.1	4.1	1.2

*Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

kg/ha at the highest application rate), uptake was not higher when compared with the check treatment. Lead concentrations in forage were generally lower due to dilution from increased plant growth with sludge and compost. As with Zn, concentrations were lower in the grain than in the forage. It is likely that the Pb was either immobile in plant roots or was unavailable due to the high soil P level.

Concentrations of Ni in both grain and forage ranged randomly among treatments from 2.6 to 6.9 ppm. In contrast, Cd concentrations were 2 to 5 times higher with compost and sludge than with $ZnSO_4$ or with no treatment. Concentrations of Cd were higher in corn forage (0.7 to 5.3 ppm) than in grain (0.2 to 1.2 ppm).

Yields of bean vines increased with compost applications and the highest rate of sludge (Table 9). As with corn there was an unexplained increase in yield with the 180 kg/ha rate of Zn as $ZnSO_4$. However, yields dropped sharply at the 360 kg/ha rate. Pod yields decreased with rate of $ZnSO_4$ application. Except for the highest rate of compost, pod yields were lower than from the check plot with all treatments. Whereas vine yields were similar with compost and sludge treatment, yields of bean pods were reduced markedly by sludge only. Van Loon (19) observed that bean pods tended to accumulate mercury (Hg) to a greater extent than vines grown on sludge-treated soil. Accordingly, bean pods may be accumulators of Zn and other heavy metals and may be less tolerant of high levels than other plant species.

Concentrations of Zn in vines increased from 60 ppm in the check to 499 ppm at the high $ZnSO_4$ rate and were about 3 times higher with sludge than with compost or the check. Levels of Zn in the bean pods were generally lower and varied less with treatment than the vines.

Despite the relatively high Pb content of the sludge, concentrations in both vines and pods grown with sludge were comparable to those from the check plots. Concentrations ranged from 3.9 to 5.5 ppm in the vines and from 0.9 to 1.8 ppm in the pods. As with corn, Ni concentrations were variable but slightly higher in pods than in vines. Sludge resulted in slightly higher concentrations of Ni in both pods and vines. Levels of Cd were low in vines and pods but were highest in vines grown with sludge.

2. Results in 1973

In the fall of 1972, all plots were subdivided with half of each plot receiving a second application of the previous treatment. The remaining half received no additional treatment so that residual effects of the original application could be measured. Nitrogen and K were applied as in 1972 to all plots.

TABLE 9. DRY YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN BEAN VINES AND PODS (1972).

Treatment	Zn rate, kg/ha	Dry yield, kg/ha		Concentration in bean vines (V) and pods (P), ppm							
				Zn		Pb		Ni		Cd	
		V	P	V	P	V	P	V	P	V	P
Check	0	990b*	1327f	60	45	5.1	1.4	5.0	5.0	0.5	0.2
$ZnSO_4$	90	1252bc	1111e	184	68	3.3	1.2	4.6	6.1	0.5	0.2
	180	1427c	252b	328	79	4.8	1.2	4.6	6.0	0.6	0.2
	360	355a	31a	499	108	3.9	1.3	4.1	5.2	0.6	0.1
Compost	90	1463c	1060e	56	56	4.9	1.4	4.3	4.1	0.5	0.2
	180	1625e	1084e	84	50	4.8	1.2	4.8	4.1	0.5	0.2
	360	1425c	1425f	52	44	4.5	1.2	3.7	3.9	0.5	0.1
Sludge	90	1231bc	1092e	158	61	4.4	0.9	6.7	6.9	1.1	0.2
	180	1234bc	858d	189	75	4.1	1.4	5.5	6.0	1.2	0.2
	360	1537d	597c	164	83	5.5	1.8	5.8	6.9	1.2	0.3

*Yields of either vines or pods followed by the same letter are not significantly different according to Duncan's Multiple Range test (5%).

Concentrations of all heavy metals extracted from soil samples from the residual half of each treated plot were equal to or slightly lower than the corresponding values obtained in 1972 (Tables 10 and 7). Apparently some immobilization of these metals occurred with time of reaction in the soil. Reapplication of treatments resulted in higher levels of extractable metals but not in proportion to the amounts applied. About half of the Zn, Cu, Pb, and Cd applied only in 1971 was recovered with the 0.5 N HCl extraction; less than one-tenth of the Cr and Ni applied in compost and sludge was recovered.

Corn forage yields were higher in 1973 than in 1972 (Table 11) probably due to the more favorable growing conditions. The spring of 1972 was unusually cool and wet; the spring of 1973 was warmer with better rainfall distribution throughout the entire growing season. Both medium and high rates of $ZnSO_4$ resulted in a significant decrease in yield compared with the check. Yields were increased with both the medium and high rates of compost applied once or reapplied. The two higher rates of sludge also resulted in yield increases but only with the single application. Differences between yields resulting from single and repeated applications were not significant with any treatment.

Total "marketable" ears of corn were reduced from about 12,000/ha for the check to 5,000 at the high rate of $ZnSO_4$ with the single application; repeated application reduced the ear count to about 1,500/ha (data not shown). The single application of all rates of compost and sludge resulted in ear production similar to that of the check. Although the second application of sludge did not influence ear count, reapplication of compost increased ear production to about 16,000/ha. Since the number of stalks per plot was relatively unaffected by treatment, total ear production was a reflection of the ear count per stalk.

Concentrations of Zn in the 1973 corn forage were higher than in 1972 even though yields also were higher (Table 11); sludge-treated plots showed the greatest increase. The second application of $ZnSO_4$ resulted in marked increases in Zn concentration in the forage; increases with sludge and compost were less pronounced. In contrast, concentrations of Zn in grain were similar in 1972 and 1973 with the single application (repeated application in 1973 resulted in slightly higher levels of Zn with $ZnSO_4$ and sludge treatments).

Concentrations of Pb in corn forage and grain were unexplainably higher in 1973 than in 1972 irrespective of treatment. However, differences in concentration due to treatment again were not evident. Further, reapplication of the waste treatments did not result in increased Pb concentration. Concentrations of Ni were lower in 1973 than in 1972 possibly as a result of dilution due to higher yields. As with Pb neither treatment nor reapplication affected concentration in forage or grain. Cadmium concentrations in forage and grain of

TABLE 10. CONCENTRATIONS OF SEVERAL HEAVY METALS IN SANGO SILT LOAM EXTRACTED BY 0.5 N HCl (1973).

Treatment	Zn rate, ppm		Concentration in soil, ppm											
			Zn		Cu		Cr		Pb		Ni		Cd	
	A*	B	A	B	A	B	A	B	A	B	A	B	A	B
Check	0	0	6	6	3	5	0.2	0.2	7	8	0.8	0.7	0.4	0.4
$ZnSO_4$	40	80	25	53	3	3	0.2	0.2	7	8	0.7	0.9	0.3	0.5
	80	160	46	106	3	3	0.2	0.2	8	8	0.7	1.0	0.6	0.4
	160	320	81	164	4	4	0.2	0.2	9	9	0.9	0.7	0.5	0.9
Compost	40	80	21	70	7	21	0.4	0.9	16	36	0.8	1.9	0.5	1.3
	80	160	34	114	9	27	0.6	1.5	25	59	1.3	3.0	0.9	1.7
	160	320	63	156	21	36	1.0	2.0	40	76	2.0	4.2	1.4	2.6
Sludge	40	80	18	68	11	27	0.5	1.7	24	62	1.0	1.9	2.6	1.4
	80	160	54	75	23	50	1.1	1.5	49	66	1.5	1.9	1.5	1.8
	160	320	73	206	31	202	1.5	4.0	68	186	1.8	4.5	2.0	4.5

*A = half of plot which received designated treatments in 1971 only; B = half of plot which received original treatment in 1971 plus an additional treatment in 1972.

TABLE 11. DRY FORAGE YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN CORN FORAGE AND GRAIN (1973).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in corn forage and grain, ppm							
					Zn		Pb		Ni		Cd	
	A*	B	A	B	A	B	A	B	A	B	A	B
					Forage							
Check	0	0	7218bc†	7067bc	47	53	10.5	7.7	1.5	1.4	1.2	1.1
$ZnSO_4$	90	180	6092b	6120b	206	509	11.0	6.4	1.8	1.9	0.9	0.8
	180	360	3186a	3768a	472	884	9.3	7.4	1.5	1.6	0.9	0.9
	360	720	4272a	2959a	644	1025	7.6	7.3	1.7	1.8	0.6	0.9
Compost	90	180	8575cde	8903de	103	126	11.2	7.7	1.8	1.6	2.4	3.0
	180	360	8934de	10581e	133	141	10.6	12.1	1.8	1.6	3.3	3.9
	360	720	8765de	10081e	122	184	6.9	17.5	1.8	1.9	3.7	5.7
Sludge	90	180	7871cd	8660cde	153	225	7.8	9.3	2.3	2.0	3.7	5.9
	180	360	8384de	8057cd	184	202	11.0	9.5	1.7	1.7	5.4	6.6
	360	720	9042de	8622cde	207	241	8.6	11.3	2.2	1.6	7.2	7.9
					Grain							
Check	0	0			35	35	2.7	2.0	1.2	0.8	0.3	0.5
$ZnSO_4$	90	180			33	57	4.3	1.6	1.9	1.2	0.3	0.3
	180	360			55	76	2.4	1.9	2.1	1.2	0.2	0.3
	360	720			72	97	2.6	2.3	1.7	1.8	0.3	0.3
Compost	90	180			41	40	1.8	1.8	1.1	0.9	0.5	0.5
	180	360			45	42	1.5	1.9	1.5	0.9	0.5	0.6
	360	720			44	42	1.7	1.0	1.5	1.3	0.7	0.8
Sludge	90	180			47	50	1.5	2.4	0.8	1.1	0.7	0.7
	180	360			46	50	2.1	2.1	1.4	1.4	0.8	1.1
	360	720			54	61	1.6	0.8	1.3	1.6	1.0	1.0

*A = half of plot which received designated treatments in 1971 only; B = half of plot which received original treatment in 1971 plus an additional treatment in 1972.

†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

the 1973 crop were comparable to those of the previous year. Levels of Cd in forage only were slightly higher with application of compost and sludge.

Yields of bean vines decreased progressively with each rate of $ZnSO_4$ whether applied only in 1971 or repeated in 1972 (Table 12). Results were similar with pods except that repeated application of the two higher Zn rates was extremely toxic and growth was negligible. Application of compost did not affect yields of either vines or pods, but the high rate of sludge reduced pod yields significantly.

Concentrations of Zn were highest with $ZnSO_4$ application, intermediate with sludge, and only slightly higher with compost as compared with the check. Apparently Zn derived from sludge was more available for plant uptake than that in compost. In general Zn concentrations in both vines and pods were comparable to those of 1972.

Levels of Pb in vines and pods were not affected by treatment or repeated application, but concentrations in pods were much higher than in 1972. Nickel uptake by bean pods from sludge plots appeared to be higher than with other treatments. As in 1972, concentrations of Cd in vines were about twice as high with sludge compared with other treatments; concentrations were similar in pods in 1972 and 1973 and were unaffected by waste treatment.

3. Results in 1974

Residual levels of most heavy metals, especially Zn, extracted from plots receiving treatment in 1971 continued to decrease in 1974 (Table 13). Concentrations were higher in acid extracts from soil receiving multiple applications of municipal wastes than from plots receiving the same total amount in a single application in 1971. These observations suggest that some reversion of Zn and other metals to less-soluble forms occurred. Liming of the $ZnSO_4$ plots in 1974 resulted in a further decrease of extractable Zn.

Corn forage yields again were highest with multiple applications of compost (Table 14). Repeated $ZnSO_4$ applications were less toxic in 1974, probably due to the higher soil pH from liming. Accordingly, concentrations of tissue Zn were much lower in 1974, especially where residual effects were being measured from the 1971 application. Levels of Cd were about the same as in 1973, being highest with sludge application. Copper, Pb, and Ni concentrations were unaffected by treatment. Zinc concentrations in corn grain were slightly lower with $ZnSO_4$ in 1974 and slightly higher with repeated compost and sludge. As in forage, Cu, Pb, and Ni levels were not affected by treatment; concentrations of Cd were higher with sludge and compost,

TABLE 12. DRY YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN BEAN VINES AND PODS (1973).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in bean vines and pods, ppm							
					Zn		Pb		Ni		Cd	
	A*	B	A	B	A	B	A	B	A	B	A	B
					Vines							
Check	0	0	1592d†	1677d	44	48	6.3	6.7	2.9	2.0	0.3	0.3
$ZnSO_4$	90	180	1225c	762b	259	305	7.4	5.5	5.3	5.8	0.7	0.6
	180	360	978b	26a	325	577	5.9	5.6	6.7	6.3	0.7	0.8
	360	720	229a	11a	466	634	4.7	7.0	5.3	6.4	0.8	0.7
Compost	90	180	1629d	1425c	68	55	5.9	7.5	4.2	3.1	0.4	0.4
	180	360	1602d	1583cd	63	55	6.5	7.1	3.1	1.7	0.4	0.4
	360	720	1481cd	1538cd	63	61	7.5	8.3	3.8	2.6	0.4	0.4
Sludge	90	180	1690d	1534d	171	225	5.0	7.0	6.7	4.5	1.0	1.1
	180	360	1521d	1476cd	184	230	6.7	7.7	6.4	4.8	0.8	1.1
	360	720	1461cd	1865e	187	211	6.0	5.8	5.3	7.1	0.9	1.3
					Pods							
Check	0	0	1296d	1254d	49	49	14.2	12.9	4.4	4.6	0.1	0.1
$ZnSO_4$	90	180	876c	631b	87	105	12.9	13.8	8.7	6.5	0.2	0.2
	180	360	363b	1a	97	-	13.6	-	7.0	-	0.2	-
	360	720	33a	1a	146	-	2.0	-	6.1	-	0.2	-
Compost	90	180	1020c	1278d	54	66	13.8	17.3	3.2	4.0	0.1	0.1
	180	360	1199cd	1264d	54	65	10.6	19.9	3.1	2.4	0.1	0.1
	360	720	1275d	1398d	54	52	13.9	14.3	2.6	2.6	0.1	0.1
Sludge	90	180	967c	1256d	72	96	12.8	8.9	9.2	8.8	0.2	0.2
	180	360	1185cd	1169cd	90	115	13.1	16.4	8.2	8.0	0.2	0.2
	360	720	926c	496b	90	101	10.2	15.4	7.2	9.6	0.2	0.2

*A = half of plot which received designated treatments in 1971 only; B = half of plot which received original treatment in 1971 plus an additional treatment in 1972.

†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

TABLE 13. CONCENTRATIONS OF SEVERAL HEAVY METALS IN SANGO SILT LOAM EXTRACTED BY 0.5 N HCl (1974).

Treatment	Zn rate, ppm		Soil pH		Concentration in soil, ppm									
					Zn		Cu		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B	A	B
Check	0	0	6.4	6.5	7	7	4	4	0.1	0.2	8	8	1.2	1.3
$ZnSO_4$	40	120	6.6	6.8	21	52	4	4	0.4	0.2	6	7	1.4	1.5
	80	240	6.2	6.2	29	97	3	3	0.4	0.2	8	8	1.5	1.5
	160	480	6.2	6.4	51	153	4	4	0.2	0.2	7	8	1.3	1.3
Compost	40	120	5.9	6.9	20	62	8	18	0.4	1.1	15	39	1.6	2.9
	80	240	6.5	7.0	31	129	12	33	0.8	2.1	23	73	1.9	4.6
	160	480	6.7	7.1	57	205	19	91	1.2	3.1	38	115	2.5	6.4
Sludge	40	120	5.2	6.0	20	143	10	21	0.6	1.6	19	67	1.7	2.3
	80	240	5.6	5.9	40	261	20	61	1.3	2.7	39	107	1.9	3.0
	160	480	5.9	6.3	62	774	30	176	2.0	6.3	66	282	2.3	6.3

*A = 1 application in 1971; B = 3 applications (1971, 1972, 1973).

TABLE 14. DRY FORAGE YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN CORN FORAGE AND GRAIN (1974).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in corn forage and grain, ppm							
					Zn		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B
					Forage							
Check	0	0	7365bc†	7674bc	28	28	0.6	0.6	3.3	4.7	1.1	1.4
$ZnSO_4$	90	270	7115b	6410ab	65	140	0.6	0.5	3.2	3.1	1.5	1.4
	180	540	7449b	5616a	88	364	0.7	0.7	3.6	4.7	1.1	1.3
	360	1080	7382b	6047a	213	467	0.8	0.8	3.7	4.1	1.3	1.3
Compost	90	270	7366b	9289d	53	68	1.1	1.8	4.6	5.6	1.1	1.1
	180	540	7642bc	9503d	55	81	1.3	2.7	3.6	4.9	1.0	1.1
	360	1080	8867cd	9240d	65	108	1.9	3.8	5.1	3.6	0.7	0.9
Sludge	90	270	6815b	8792cd	98	172	2.8	4.4	4.0	4.7	1.3	1.2
	180	540	7925c	8611c	94	221	3.5	5.2	2.9	4.3	1.2	1.6
	360	1080	8651c	8524c	130	250	4.8	5.4	4.9	4.0	1.2	1.2
					Grain							
Check	0	0			35	40	0.2	0.2	1.0	0.8	0.7	0.5
$ZnSO_4$	90	270			46	49	0.2	0.3	1.4	1.1	0.7	0.8
	180	540			49	61	0.2	0.2	1.1	0.7	0.6	0.8
	360	1080			57	67	0.1	0.2	0.8	1.4	0.9	1.2
Compost	90	270			45	50	0.2	0.3	0.9	1.1	1.0	0.4
	180	540			45	53	0.2	0.3	0.9	1.5	1.1	0.9
	360	1080			46	55	0.4	0.6	1.0	1.4	1.2	0.9
Sludge	90	270			48	59	0.5	0.5	0.8	1.3	1.0	1.0
	180	540			49	65	0.5	0.6	0.9	1.3	1.2	1.3
	360	1080			63	75	0.6	0.7	0.9	1.3	0.8	0.9

*A = 1 application in 1971; B = 3 applications (1971, 1972, 1973).
†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

but levels were less than 1 ppm. Total marketable ears of sweet corn were reduced with repeated applications of $ZnSO_4$ even though this apparent toxicity was not reflected in depressed forage yields (data not shown). High rates of both compost and sludge increased yields of marketable ears.

Dry matter production of bean vines was lower in 1974 compared with 1973 (Table 15). However, as with corn, the toxic effect of $ZnSO_4$ was diminished considerably. Concentrations of Zn were lower with $ZnSO_4$, slightly higher with compost, and much higher with sludge in 1974 than in previous years. Copper and Pb contents were not affected by treatment and levels were similar to past year's results. Levels of Cd and Ni were three- and twofold higher, respectively, with sludge application.

Bean yields averaged about half of the 1973 production (Table 15). In contrast to corn, bean yields did not increase with municipal waste application. Although some depression in yields occurred with the higher rates of sludge, differences were probably not significant since yields were variable. Levels of Zn were about twice as high with $ZnSO_4$ and sludge treatments applied for 3 years; concentrations with compost were similar to check values. Concentrations of Ni were 2 to 3 times higher with sludge than with other treatments. As in corn grain, levels of Cd were slightly higher with sludge but less than 1 ppm.

4. Results in 1975

Soil samples from treated plots were extracted with a DTPA solution according to the procedure outlined by Lindsay and Norvell (10). Based on previous experience this extractant removes about half as much Zn, Cu, and Cd from soil as 0.5 N HCl; lesser amounts of Ni and Pb are extracted. Results show that similar amounts of Zn were recovered from plots amended in 1971 with $ZnSO_4$, compost, and sludge (Table 16). However, after multiple applications, considerably less Zn was extracted from compost-treated soils than from the $ZnSO_4$ or sludge plots. Possibly the complexing capacity of the compost for Zn is responsible. Whereas repeated application of each treatment increased extractable Zn from three- to sevenfold, the other heavy metals were increased only two- to threefold.

Forage yields of sweet corn were not appreciably affected by $ZnSO_4$ or waste treatments applied in 1971 (Table 17). In contrast to previous years, yield increases of marketable ears were not obtained with increases in rate of compost application. This might be due to ample moisture during the growing season which probably negated any benefit

TABLE 15. DRY YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN BEAN VINES AND PODS (1974).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in bean vines and pods, ppm							
					Zn		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B
					Vines							
Check	0	0	1119c†	1011bc	53	63	0.4	0.4	7.3	7.7	2.9	2.5
$ZnSO_4$	90	270	1053bc	965b	123	266	0.4	0.4	6.8	5.0	3.1	2.6
	180	540	905b	587a	254	360	0.5	0.5	8.5	6.6	3.1	2.9
	360	1080	921b	618a	346	391	0.5	0.5	7.6	5.6	3.0	2.4
Compost	90	270	1244cd	1214cd	80	73	0.4	0.5	7.6	6.7	2.7	2.6
	180	540	1195c	1419d	85	91	0.5	0.5	7.3	8.3	2.8	2.5
	360	1080	1260cd	1472d	76	94	0.5	0.6	8.0	8.3	2.5	2.3
Sludge	90	270	774ab	920b	282	404	1.2	1.5	7.7	8.9	5.3	5.5
	180	540	1178c	1247cd	254	410	1.0	1.3	8.4	8.2	4.7	5.9
	360	1080	1136c	1284cd	296	338	1.1	1.5	10.1	7.3	5.0	5.7
					Pods							
Check	0	0	757cd	645bc	59	60	0.1	0.2	2.3	2.8	4.0	3.5
$ZnSO_4$	90	270	785cd	710c	73	87	0.1	0.2	2.3	2.8	4.1	4.0
	180	540	571b	398a	103	106	0.1	0.2	2.1	2.4	4.1	3.2
	360	1080	855d	541b	101	150	0.1	0.2	2.3	2.5	3.9	2.2
Compost	90	270	567b	774cd	68	66	0.1	0.3	2.2	2.2	3.6	4.3
	180	540	664bc	749c	65	62	0.1	0.3	2.5	2.7	4.0	2.5
	360	1080	727c	577b	62	65	0.1	0.2	2.3	3.4	2.9	3.1
Sludge	90	270	473ab	616bc	86	144	0.2	0.3	1.9	2.9	11.4	9.5
	180	540	636bc	492ab	91	130	0.2	0.2	2.4	2.7	10.0	9.9
	360	1080	617bc	491ab	87	115	0.2	0.2	2.5	2.2	9.1	12.0

*A = 1 application in 1971; B = 3 application (1971, 1972, 1973).
†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

TABLE 16. CONCENTRATIONS OF SEVERAL HEAVY METALS IN SANGO SILT LOAM EXTRACTED BY DTPA (1975).

Treatment	Zn rate, ppm		Soil pH		Concentration in soil, ppm									
					Zn		Cu		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B	A	B
Check	0	0	6.3	5.8	2	2	9	1	0.1	0.1	2	2	0.1	0.1
$ZnSO_4$	40	160	6.0	6.0	7	27	2	1	0.1	0.1	2	2	0.1	0.1
	80	320	5.8	6.0	12	74	1	1	0.1	0.1	2	2	0.1	0.2
	160	640	6.0	6.0	22	129	1	1	0.1	0.1	2	2	0.2	0.1
Compost	40	160	5.5	6.8	6	19	2	7	0.2	0.4	5	10	0.2	0.3
	80	320	6.6	7.0	16	27	6	10	0.4	0.7	8	15	0.3	0.5
	160	640	6.8	7.3	19	63	7	17	0.5	1.2	11	24	0.3	0.8
Sludge	40	160	5.5	5.0	9	69	4	11	0.3	0.7	4	11	0.3	0.6
	80	320	5.7	5.3	19	77	7	15	0.5	0.9	7	13	0.4	0.7
	160	640	6.1	5.7	25	157	110	33	0.8	1.9	11	29	0.5	1.5

*A = 1 application in 1971; B = 4 applications (1971, 1972, 1973, 1974)

TABLE 17. DRY FORAGE YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN CORN FORAGE AND GRAIN (1975).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in corn forage and grain, ppm							
					Zn		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B
					Forage							
Check	0	0	7233bc†	8147cd	30	46	0.7	0.7	4.2	5.1	0.8	0.8
$ZnSO_4$	90	360	7984cd	7208bc	69	225	0.8	0.8	4.6	5.2	0.8	0.8
	180	720	7047bc	6670ab	93	366	0.6	0.9	4.1	4.5	0.9	1.0
	360	1440	8710d	6637ab	94	600	1.0	0.9	4.2	4.5	0.9	0.8
Compost	90	360	6518a	6418a	88	89	1.9	2.0	5.4	5.0	1.0	0.8
	180	720	6828b	6239a	81	114	1.9	2.5	4.9	5.5	0.8	0.8
	360	1440	7674c	6858b	74	150	2.0	3.5	4.7	5.3	1.1	1.1
Sludge	90	360	6414a	6987b	130	313	3.4	4.9	4.1	5.5	0.9	0.8
	180	720	7038bc	6716ab	158	450	4.7	6.6	5.2	5.1	1.0	0.9
	360	1440	7883cd	7448c	172	400	5.9	7.0	5.7	5.0	1.2	1.1
					Grain							
Check	0	0			36	32	0.2	0.2	0.7	1.1	0.6	0.6
$ZnSO_4$	90	360			40	54	0.2	0.2	1.0	1.2	0.5	0.6
	180	720			49	67	0.3	0.3	1.0	1.1	0.7	0.8
	360	1440			50	68	0.2	0.3	1.1	1.1	0.5	0.6
Compost	90	360			46	46	0.4	0.4	1.6	1.2	0.8	0.8
	180	720			43	46	0.4	0.7	1.0	1.2	0.6	0.8
	360	1440			44	46	0.4	0.6	1.3	0.9	0.7	0.7
Sludge	90	360			45	62	0.8	0.9	1.1	1.3	0.7	0.9
	180	720			48	74	0.9	1.0	1.2	1.1	1.0	0.9
	360	1440			51	64	1.0	1.2	1.0	1.3	1.0	1.1

*A = 1 application in 1971; B = 4 applications (1971, 1972, 1973, 1974)
†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

from the organic wastes in terms of moisture relationships. No toxic effects of Zn were evident even where repeated applications of $ZnSO_4$ totaled 1,440 kg of Zn/ha.

Concentrations of Zn in corn forage from plots amended with compost and sewage sludge were higher than in 1974 (Table 17); levels in $ZnSO_4$-treated plots were similar. No differences in grain Zn were found as a result of treatment and levels were comparable to those in crops of previous years. Concentrations of Cd were higher in 1975 in both forage and grain from plots receiving sewage sludge. As in previous years, Pb and Ni concentrations were not increased as a result of organic waste application.

In 1975 the bean cultivar 'White Half Runner' was replaced with 'Contender,' a true bush bean. The change was made to determine whether the sensitivity of the 'White Half Runner' to Zn would also apply to another cultivar. Other studies have shown that varietal differences ranging from three- to tenfold may occur in terms of tolerance to toxic levels of metals. Yields of 'Contender' vines were somewhat higher and pods lower than with the 1974 'White Half Runner' crop (Table 18). This may have been due to the later harvest of more mature beans in 1974. Despite this difference in maturity and cultivar, response to $ZnSO_4$ and the waste products was quite similar. Yields of vines and pods were reduced slightly with the residual $ZnSO_4$ and markedly with the repeated treatment. Again, compost effects were negligible. Lowest yields were obtained with multiple applications of sludge due at least in part to the lower soil pH values associated with these treatments.

Trends in heavy metal concentrations in beans were similar to those in 1974 (Table 15). Residual Zn availability from $ZnSO_4$ and sewage sludge was similar as manifested in vine and pod concentrations. However, repeated treatments resulted in higher Zn levels with sludge due likely to lower soil pH. Whereas Zn concentrations increased with rate of Zn as $ZnSO_4$, levels with sewage sludge were not related to rate. Despite the application of 1,440 kg/ha of Zn in compost, concentrations were only slightly in excess of check values in vines and pods.

Copper concentrations were slightly higher in beans grown on sludge-treated plots with no differences between residual and repeated application. Levels of Cd were highest with sludge, especially in vine tissue. Lead concentrations were somewhat higher in vines but not in pods from sludge-amended plots. As in 1973 and 1974, concentrations of Ni were higher with sludge, especially in pods.

TABLE 18. DRY YIELDS AND CONCENTRATIONS OF SEVERAL HEAVY METALS IN BEAN VINES AND PODS (1975).

Treatment	Zn rate, kg/ha		Dry yield, kg/ha		Concentration in bean vines and pods, ppm									
					Zn		Cu		Cd		Pb		Ni	
	A*	B	A	B	A	B	A	B	A	B	A	B	A	B
							Vines							
Check	0	0	1658cd†	1606c	42	36	9.3	8.7	0.2	0.2	5.4	5.9	2.2	2.2
$ZnSO_4$	90	360	1435bc	1271ab	47	101	8.9	9.1	0.2	0.2	5.5	5.5	2.4	2.3
	180	720	1492bc	1234ab	67	226	9.2	8.9	0.2	0.3	5.9	6.7	2.1	2.3
	360	1440	1365b	929a	118	288	9.3	8.6	0.3	0.4	5.8	5.9	2.3	2.2
Compost	90	360	1538c	1630cd	57	43	9.0	9.3	0.4	0.2	6.0	6.0	2.1	2.1
	180	720	1746d	1685cd	51	46	9.7	9.8	0.2	0.3	5.4	6.1	2.1	2.2
	360	1440	1680cd	1584c	53	50	10.2	9.6	0.3	0.2	6.4	6.5	2.4	2.1
Sludge	90	360	1224ab	1173ab	128	304	10.8	10.4	0.8	1.1	6.7	7.2	4.5	4.4
	180	720	1417b	1028a	141	325	10.6	9.7	1.0	1.4	6.6	7.2	4.9	4.6
	360	1440	1550c	1080a	128	308	10.8	11.0	0.8	1.3	6.7	7.3	3.7	5.5
							Pods							
Check	0	0	558cd	516bc	53	52	10.6	10.5	0.1	0.1	2.4	2.5	2.9	2.5
$ZnSO_4$	90	360	483b	545c	56	70	11.0	11.1	0.1	0.1	2.3	2.7	2.5	2.4
	180	720	524c	549c	61	94	11.0	11.1	0.1	0.1	2.3	2.5	2.3	2.4
	360	1440	508bc	358a	79	107	11.3	11.3	0.1	0.1	2.2	2.5	2.3	2.2
Compost	90	360	610d	582cd	58	60	11.3	10.4	0.1	0.1	2.3	2.3	2.2	2.1
	180	720	534c	544c	56	56	10.5	10.8	0.1	0.1	2.5	2.6	1.8	2.3
	360	1440	529c	548c	54	52	9.8	9.4	0.1	0.1	2.5	2.5	2.2	2.0
Sludge	90	360	482b	429ab	71	111	11.1	11.7	0.2	0.2	2.4	2.4	8.7	7.2
	180	720	492b	326a	82	127	12.3	11.5	0.2	0.3	3.0	2.5	8.7	8.1
	360	1440	438ab	295a	79	115	11.5	12.9	0.2	0.3	2.6	2.7	6.9	8.9

*A = 1 application in 1971; B = 4 applications (1971, 1972, 1973, 1974)
†Yields followed by the same letter are not significantly different according to Duncan's Multiple Range Test (5%).

C. HEAVY METAL CONTENT OF SEVERAL VEGETABLE SPECIES GROWN IN SOIL AMENDED WITH SEWAGE SLUDGE

Since the previous study indicated that corn and beans differ in capacity to accumulate Zn and other heavy metals from municipal waste-amended soils, the present study compared response of several other vegetables to heavy metals contained in two sewage sludges differing in composition (5).

Anaerobically digested sewage sludges from Tuscumbia and Decatur, Alabama, were each applied at a rate of 112 metric tons/ha of dry product in the fall of 1973 to an area next to the experimental site of the previous study. Also, 100 kg each of N and K as NH_4NO_3 and KCl, respectively, were applied and disked into the soil during the spring of 1974 and 1975. Seeds of all vegetables (Tables 22 and 23) were sown except peppers, tomatoes, and lettuce, which were transplanted. Overhead sprinkler irrigation was used to maintain adequate soil moisture.

Vegetables were harvested from triplicate plots (3 by 5 meters) as they matured and total yields were measured. Samples of leaves and edible plant parts were taken midway through the growing season and washed thoroughly with distilled water before drying at 80C. Grinding and heavy-metal analysis were done as described in the previous experiment. Soil samples were taken from the plots at about the same time as the plant samples were taken. Portions of air-dried soil were extracted with 0.5 N HCl, 0.5 N HNO_3, and DTPA and analyzed for heavy metals as discussed earlier. Similarly, 5-gram portions of air-dried Tuscumbia and Decatur sewage sludges were extracted with each acid, DTPA, and water, and analyzed for the same heavy metals.

Less than 1% of the heavy metal content of the Tuscumbia or Decatur sludges was extracted by water, whereas the acid extractants removed from 49% to 100% (Table 19). Recovery with DTPA ranged from 9% to 46%. In general, dissolution of the metals by 0.5 N HCl and 0.5 N HNO_3 was similar. Dissolution by the acids of the metals from the Tuscumbia and Decatur sludges was in the order: Zn > Cu > Cd > Pb > Ni and Zn = Cd > Cu > Pb > Ni, respectively. Dissolution in dilute acid and DTPA differed within a particular sludge and also varied from one sludge to another. In the case of Cu, this may be related to the composition of the organic component of the sludge which is probably responsible for complexing or bonding of Cu.

TABLE 19. HEAVY METALS EXTRACTED BY WATER AND ACIDS FROM TUSCUMBIA AND DECATUR SEWAGE SLUDGES.

Sewage Sludge	Extractant	Solubility in extractant, % of total				
		Cu	Zn	Cd	Ni	Pb
Tuscumbia	H_2O	0.4	0.6	0.6	0.9	0.1
	0.5 N HNO_3	83	98	76	49	70
	0.5 N HCl	88	94	81	56	69
	DTPA	46	27	35	25	9
Total, ppm*		516	3640	35	43	1560
Decatur	H_2O	1.0	0.7	0.4	0.8	0.1
	0.5 N HNO_3	85	100	100	58	77
	0.5 N HCl	77	100	100	58	73
	DTPA	30	26	45	17	17
Total, ppm*		740	1840	49	40	525

*Determined by dry ashing 2.0 grams of dry sludge for 6 hours at 470C.

Soil samples taken in 1974 from plots amended with sewage sludge were similarly extracted (Table 20). As with the sludge, 0.5 N HCl and 0.5 N HNO_3 extracted similar amounts of heavy metals from soil. Most of the Cu, Zn, Cd, Ni, and Pb in the soil amended with Decatur sludge was extracted; lesser amounts were recovered from soil treated with Tuscumbia sludge. This probably reflects the difference between these waste products with regard to chemical forms of the elements, types of bonding, and rate of organic matter decomposition. Application of Tuscumbia sludge to the soil appeared to reduce the solubility of Cu, Zn, Cd, Ni, and Pb, but the solubility of Ni and Pb in Decatur sludge increased after soil application. Recovery of metals by acid extraction was slightly greater in 1975, suggesting an increase in plant availability (Table 21). Although recovery of all metals was less with DTPA than with acid, patterns were similar.

Yields of most vegetable species grown in 1974 were relatively unaffected by sludge application (Table 22). However, tomato yields increased from 23 to 30 kg and summer squash from 43 to 73 kg/plot with Tuscumbia sludge. Yields with Decatur sludge were slightly lower. Favorable response to municipal waste products also has been reported by Terman and Mays (17), Hortenstine and Rothwell (8), and Giordano, Mortvedt, and Mays (7). Application rates of garbage compost or sewage sludge up to 400 metric tons/ha resulted in yield increases of various crops in these studies.

Except for the leafy vegetables, radish and turnip roots were the greatest accumulators of Zn and Cd. Highest concentrations of Zn were found in lettuce, spinach, and radish leaves, and content of Cu was high in lettuce, tomato, squash, and pepper leaves. Among the leafy vegetables, lettuce was the greatest accumulator of Zn, Cu, and Cd. Other investigators (12, 15) have also reported that heavy metal content of leaf tissue is generally higher than in roots, seeds, or fruits of vegetables.

Cadmium concentrations were higher with Decatur than with Tuscumbia sludge, especially in lettuce and the root crops. Although slight increases in Ni concentrations occurred with applied sludge, no significant species differences were noted. Concentrations of Pb were determined but not reported, since there was little variation due to waste treatment. Levels in leaf tissue were normally higher than in fruits or roots but species differences were not significant. Possibly because of limited mobility of these elements in plants and, therefore, restricted translocation to the reproductive parts, vegetables consumed as fruits or seed pods may be relatively free from heavy metal contamination.

Yields of most plant species grown in 1975 were lower than in 1974 (Table 23). An extremely wet season in 1975 resulted in uncontrollable weed and disease problems, thus necessitating an early termination of

TABLE 20. HEAVY METALS EXTRACTED BY ACIDS FROM SOIL AMENDED WITH TUSCUMBIA AND DECATUR SEWAGE SLUDGES (1974).

Sewage sludge	Extractant	Solubility in extractant, % of total applied				
		Cu	Zn	Cd	Ni	Pb
Tuscumbia	0.5 N HNO_3	64	84	56	32	61
	0.5 N HCl	50	91	50	36	65
Total, ppm*		26	182	1.8	2.2	78
Decatur	0.5 N HNO_3	100	100	100	100	100
	0.5 N HCl	100	100	100	85	92
Total, ppm*		37	92	2.5	2.0	26

*Based on application rate of 112 metric tons/ha of dry sludge.

TABLE 21. HEAVY METALS EXTRACTED BY 0.5 N HCl AND DTPA FROM SOIL AMENDED WITH TUSCUMBIA AND DECATUR SEWAGE SLUDGES (1975).

Sewage sludge	Extractant	Solubility in extractant, % of total applied				
		Cu	Zn	Cd	Ni	Pb
Tuscumbia	0.5 N HCl	75	100	67	36	77
	DTPA	22	39	24	10	9
Total, ppm*		26	182	1.8	2.2	78
Decatur	0.5 N HCl	100	100	100	60	100
	DTPA	47	54	57	27	17
Total, ppm*		37	92	2.5	2.0	26

*Based on application rate of 112 metric tons/ha of dry sludge.

TABLE 22. TOTAL YIELD AND CONCENTRATIONS OF HEAVY METALS IN VEGETABLES, AS AFFECTED BY SLUDGE TREATMENT (1974).

Species	Treatment	Yield, kg/plot	Fruit or root conc. ppm				Leaf concentration ppm			
			Zn	Cu	Cd	Ni	Zn	Cu	Cd	Ni
Beans	None	7	21	7.9	0.04	1.3	40	6.0	0.46	2.6
(*Phaseolus*	Decatur	7	31	7.6	0.23	2.7	179	7.8	1.70	3.5
limensis)	Tuscumbia	6	28	7.4	0.07	1.8	95	5.8	0.55	2.4
Okra	None	12	40	9.2	0.13	0.7	41	6.9	0.59	1.9
(*Hibiscus*	Decatur	11	61	9.0	0.60	0.7	94	10.0	2.00	2.8
esculentus)	Tuscumbia	11	43	8.3	0.16	0.7	55	7.1	0.59	1.8
Peppers	None	23	23	10.4	0.09	1.0	68	19.0	0.71	1.7
(*Capsicum*	Decatur	25	41	13.4	0.40	2.3	143	21.0	2.70	2.7
spp.)	Tuscumbia	20	31	10.5	0.14	1.6	92	18.0	0.76	2.1
Tomato	None	23	15	3.4	0.12	1.8	49	19.0	0.66	1.5
(*Lycopersicon*	Decatur	29	24	3.8	0.39	3.3	77	22.0	2.10	2.3
esculentum Mill.	Tuscumbia	30	20	2.9	0.20	0.7	55	18.0	0.75	1.6
Squash	None	43	47	12.8	0.03	0.9	93	14.0	0.34	1.7
(*Cucurbita*	Decatur	67	83	15.3	0.20	2.6	233	19.0	0.63	4.0
pepo L.)	Tuscumbia	73	93	12.8	0.15	1.6	226	15.0	0.36	2.2
Turnip	None	13	39	5.5	0.42	1.8	52	6.3	0.59	2.9
(*Brassica*	Decatur	14	133	8.9	1.30	2.8	194	9.4	2.60	4.0
rapa)	Tuscumbia	13	73	6.5	0.42	2.1	96	7.3	0.59	2.9
Radish	None	--	48	3.2	0.29	3.0	56	5.5	0.92	3.9
(*Raphanus*	Decatur	--	149	3.8	0.92	3.7	275	7.5	3.10	6.0
sativus L.)	Tuscumbia	--	121	3.3	0.33	2.6	271	3.8	0.88	5.1
Kale	None	11	-	--	--	-	33	6.0	0.63	1.8
(*Brassica*	Decatur	11	-	--	--	-	161	8.1	2.30	3.5
oleracea)	Tuscmubia	13	-	--	--	-	113	7.6	0.63	2.4
Lettuce	None	--	-	--	--	-	71	12.9	1.00	2.2
(*Lactuca*	Decatur	--	-	--	--	-	212	22.8	8.60	3.8
sativa L.)	Tuscumbia	--	-	--	--	-	336	21.0	3.00	3.9
Spinach	None	--	-	--	--	-	168	9.1	1.00	2.3
(*Spinacia*	Decatur	--	-	--	--	-	163	12.7	2.80	2.9
oleracea)	Tuscumbia	--	-	--	--	-	225	10.0	0.84	2.1

TABLE 23. TOTAL YIELD AND CONCENTRATIONS OF HEAVY METALS IN VEGETABLES, AS AFFECTED BY SLUDGE TREATMENT (1975).

Species	Treatment	Yield, kg/plot	Fruit or root conc. ppm				Leaf concentration ppm			
			Zn	Cu	Cd	Ni	Zn	Cu	Cd	Ni
Okra	None	13	48	10.7	0.42	1.4	56	15.4	0.67	1.8
	Decatur	16	55	10.7	1.20	1.4	53	14.1	3.10	1.7
	Tuscumbia	13	49	10.7	0.39	1.4	76	14.1	0.44	1.8
Pepper	None	8	32	12.1	0.04	1.5	61	14.7	1.04	2.3
	Decatur	8	43	10.7	0.60	2.4	153	15.4	2.92	3.0
	Tuscumbia	6	40	10.1	0.12	1.3	130	15.4	0.78	2.4
Tomato	None	7	34	11.4	0.33	1.1	36	21.4	1.70	2.5
	Decatur	12	37	11.4	1.12	1.2	79	19.4	6.70	2.8
	Tuscumbia	9	36	11.4	0.40	1.3	61	22.8	1.70	2.2
Squash	None	38	65	12.7	0.27	1.5	112	16.1	0.70	2.6
	Decatur	40	90	12.7	0.72	1.9	233	12.1	2.15	4.4
	Tuscumbia	30	88	12.7	0.19	1.7	287	9.4	0.87	2.9
Lettuce	None	4	--	--	--	-	109	17.4	1.20	3.9
	Decatur	5	--	--	--	-	166	18.1	7.00	4.4
	Tuscumbia	4	--	--	--	-	316	12.7	2.60	4.9

the experiment. None of the vegetables grown in 1975 responded to sludge amendment.

Concentrations of Zn, Cd, and Ni were slightly higher in both fruit and leaf tissue in 1975 than in 1974. Levels of these heavy metals were also higher in the plants grown on the check plots, possibly as a result of the drop in soil pH from 6.4 in 1974 to 5.8 in 1975. Cadmium increased in all species grown on plots receiving Decatur sewage sludge. However, there was little indication that the Cd present in Tuscumbia sewage sludge was available for plant uptake, since concentrations in treated plants were comparable to those in plants grown in untreated plots. This might be explained by the higher total and extractable content of Cd in the Decatur waste material.

Heavy metal uptake was consistently higher from Decatur than from Tuscumbia sewage sludge with all vegetables. Even though the total Zn content of the Tuscumbia sludge (3,640 ppm) was higher than that of the Decatur sludge (1,840 ppm), uptake was greater from the latter. Generally, plant availability of the heavy metals contained in the waste materials was not related to either the total content or the fraction extracted by acid or DTPA. Uptake results (Tables 22 and 23) relate well to soil extraction data (Tables 20 and 21), which show that a greater percentage of all metals was extracted by 0.5 N HCl or HNO_3 from the Decatur sludge. Furthermore, slightly higher heavy metal concentrations in plants in 1975 than in 1974 were associated with greater recovery from amended soil in 1975 by acid extraction.

D. INFLUENCE OF SOIL HEATING ON PLANT AVAILABILITY OF HEAVY METALS APPLIED IN MUNICIPAL SEWAGE SLUDGE

Several beneficial uses of waste heat from nuclear and fossil fueled power production have been suggested. One outlet being considered is soil heating which in some instances could extend the growing season of certain crops. The objective of the present study was to determine whether soil heating affects release of heavy metals from sludge-amended soil by increasing the rate of organic matter decomposition. If there is a significant increase in rate, plant availability of heavy metals could be increased, the result being temporary toxicity before reversion to less-soluble forms.

Municipal sewage sludge from Decatur, Alabama, was applied to Sango silt loam (pH 5.1) at a rate of 224 metric tons/ha in the fall of 1974. Electric heating cables were installed at a depth of 30 cm and thermostatically controlled to heat the soil to a temperature of 27C (with a total heating capacity of 107 watts/meter^2). Cables were also installed in an unamended plot. Ammonium nitrate and KCl were applied uniformly over the untreated and sludge-treated plots to supply 100 kg each of N and K/ha. Lettuce, bell peppers, pole beans, sweet corn, and summer squash were planted in April 1975. Yields were recorded throughout the growing season. Soil and plant samples were taken during midsummer for analysis of Zn, Cd, Cu, Ni, and Pb.

Yields of all crops except sweet corn were reduced by soil heating with or without sewage sludge (Table 24). Corn yields were not affected by heating. Sludge application resulted in higher yields of all crops without soil heating. Although corn and squash yields were also increased with sludge in heated soil, yields of lettuce, peppers, and beans were slightly lower.

Among the vegetables being investigated, lettuce was the greatest accumulator of most of the heavy metals; corn leaves were high in Zn and Cd, but the kernels were not excessively high (Table 25). Soil heating had no consistent effect on heavy metal concentrations except for Cd. Concentrations of Cd were higher in both leaf and fruit tissue of all species grown on the heated than on the nonheated check plots. Since soil heating did not result in higher Cd concentrations where sludge was applied, it appeared that the higher concentrations in plants from the heated checks were related to release of soil Cd. However, soil extraction with both DTPA and 0.5 N HCl resulted in greater recovery of all heavy metals from heated than from nonheated soils regardless of sludge application (Table 26).

TABLE 24. EFFECT OF SEWAGE SLUDGE AND SOIL HEATING ON VEGETABLE YIELDS.

Species	Dry weight, kg/plot			
	Check No heat	Check Heated	Sludge Heated	Sludge No heat
Lettuce	4.2	2.6	2.2	4.7
Pepper	5.3	5.0	4.5	6.5
Bean	8.4	7.2	6.3	10.2
Corn	10.2 (37)*	11.0 (43)	14.8 (53)	14.9 (55)
Squash	30.6	25.9	38.4	43.4

*Values in parentheses represent numbers of marketable ears.

TABLE 25. EFFECT OF SEWAGE SLUDGE AND SOIL HEATING ON HEAVY METAL CONCENTRATIONS IN FRUIT AND LEAVES OF SEVERAL VEGETABLES.

Species	Treatment	Fruit concentration, ppm					Leaf concentration, ppm				
		Zn	Cu	Pb	Ni	Cd	Zn	Cu	Pb	Ni	Cd
Lettuce	Check, no heat						54	13	3.6	3.5	0.30
	Check, heated						44	10	3.0	3.0	0.60
	Sludge, heated						142	27	7.7	6.3	10.00
	Sludge, no heat						131	19	5.8	7.4	10.40
Pepper	Check, no heat	36	25	1.3	2.8	0.25	71	17	5.1	4.6	0.90
	Check, heated	36	20	1.4	2.4	0.40	64	16	5.3	3.1	1.30
	Sludge, heated	42	23	1.4	2.1	1.70	96	18	6.7	3.3	6.33
	Sludge, no heat	45	26	1.4	2.2	1.30	109	20	6.4	2.9	7.51
Bean	Check, no heat (P)*	31	21	2.3	2.9	0.14	37	13	6.5	3.7	0.16
	Check, no heat (S)*	64	22	2.9	6.9	0.07					
	Check, heated (P)	33	20	2.3	2.9	0.22	46	14	5.2	4.6	0.20
	Check, heated (S)	66	20	3.2	6.8	0.06					
	Sludge, heated (P)	49	17	2.9	3.4	0.49	62	12	5.1	3.7	0.83
	Sludge, heated (S)	72	18	2.9	4.6	0.32					
	Sludge, no heat (P)	51	18	3.0	3.4	0.35	71	12	6.6	4.1	0.72
	Sludge, no Heat (S)	73	19	2.8	5.6	0.21					
Corn	Check, no heat	25	5.3	1.1	0.4	0.10	52	8	4.0	2.2	0.29
	Check, heated	30	5.3	1.1	0.6	0.29	54	9	3.9	2.4	0.93
	Sludge, heated	37	4.1	1.1	0.6	1.40	178	14	4.5	2.2	19.10
	Sludge, no heat	40	6.3	1.3	0.8	1.83	142	12	4.5	2.2	16.30
Squash	Check, no heat	43	19	1.7	2.1	0.15	48	9	7.9	3.0	0.15
	Check, heated	39	18	1.7	2.3	0.18	88	10	7.0	3.3	1.00
	Sludge, heated	44	21	1.4	2.0	0.24	121	14	9.7	3.5	1.93
	Sludge, no heat	50	21	1.7	1.9	0.27	120	14	9.2	3.3	1.40

*P = pods only; S = shelled beans.

TABLE 26. EFFECT OF SOIL HEATING ON EXTRACTION OF HEAVY METALS FROM SOILS AMENDED WITH SEWAGE SLUDGE.

Treatment	DTPA extractable, ppm					0.5 N HCl extractable, ppm				
	Zn	Cu	Pb	Ni	Cd	Zn	Cu	Pb	Ni	Cd
Check, no heat	0.5	1.1	1.6	0.15	0.03	2.0	1.0	5.3	0.6	0.08
Check, heated	0.6	1.4	1.9	0.16	0.05	2.9	2.6	6.2	0.6	0.12
Sludge, heated	10.0	18.9	6.6	0.21	1.20	112.8	62.8	38.4	1.6	3.70
Sludge, no heat	9.1	14.8	5.6	0.15	1.00	74.2	43.5	27.8	1.2	2.60

SECTION VI

GREENHOUSE POT STUDIES

A. PLANT UPTAKE OF HEAVY METALS FROM SEWAGE SLUDGE AS AFFECTED BY SOIL pH

Although the availability of Zn to plants decreases with rise in soil pH, the literature suggests that pH has less effect on the availability of Cd and other heavy metals. The purpose of this greenhouse experiment was to determine whether liming an acid soil significantly depresses uptake of heavy metals present in anaerobically digested sewage sludge.

Mountview silt loam was limed to pH values of 5.0, 6.0, and 7.0 with a 4:1 mixture of $CaCO_3$ and $MgCO_3$. The following nutrients were mixed with 2 kg of soil at the rates indicated: NH_4NO_3--400 mg of N; concentrated superphosphate--200 mg of P; K_2SO_4--200 mg of K. Decatur and Tuscumbia sewage sludges were also mixed with the soil to provide both 40 and 200 grams of dry matter per pot. An inorganic heavy metal supplement was mixed with the soil in a third series of pots to supply Zn, Cu, Cd, Ni, and Pb at rates equal to those provided by 40 grams of the Tuscumbia sewage sludge. Mustard (Sinapis alba) seeds were sown in January 1975, and thinned to 12 plants per pot. Leaves were harvested three times over a period of 10 weeks, allowing enough time for regrowth between harvests. Plant tissue was dried, weighed, crushed, and analyzed for heavy metal content.

Mustard yields increased with soil pH among most treatments and sludge rates (Table 27); Tuscumbia sludge was very toxic at the 200-gram rate at all pH values. Inorganic heavy metals equivalent to 40 grams of Tuscumbia sludge were more toxic than the sludge at pH 5.0 only. Yields were highest at all pH values with Decatur sludge, probably due in part to its liming effect.

Uptake of Zn varied inversely with soil pH. Although uptake was sometimes higher with Decatur than with Tuscumbia sludge, concentration was less due to growth dilution. The higher Zn concentrations associated with the Tuscumbia sludge treatment likely account for the poor growth of mustard, especially at the high rate of application. Toxicity was apparent when concentrations of Zn in the plant tissue exceeded 500 ppm. This is in general agreement with other published data.

Cadmium uptake was highest at pH 5.0, but differences between pH 6.0 and 7.0 were not great. The higher Cd content of the Decatur than of the Tuscumbia sludge was reflected in higher plant uptake. Uptake of Cu, Pb, and Ni was not affected by soil pH. Whereas Cu levels were higher with Decatur than with Tuscumbia sludge, levels of Pb and Ni were smaller with both sludge treatments.

TABLE 27. TOTAL DRY MATTER YIELD AND HEAVY METAL UPTAKE BY MUSTARD AS AFFECTED BY SOIL pH AND SEWAGE SLUDGE APPLICATION.

Soil pH	Sewage sludge	Rate, grams/pot	Dry matter, grams/pot	Heavy metal uptake, mg/pot				
				Zn*	Cd	Cu	Pb	Ni
5.0	None	-	11.4	1.02 (89)	.02	.04	.07	.03
		†	--	--	-	-	-	-
	Decatur	40	18.8	8.24 (438)	.17	.19	.11	.10
		200	24.7	8.36 (338)	.32	.44	.17	.10
	Tuscumbia	40	5.7	7.57 (1328)	.06	.15	.05	.06
		200	--	--	-	-	-	-
6.0	None	-	20.9	0.83 (40)	.02	.08	.13	.04
		†	21.3	8.22 (386)	.20	.26	.12	.15
	Decatur	40	25.1	3.06 (143)	.11	.23	.17	.07
		200	24.1	4.40 (183)	.22	.42	.15	.07
	Tuscumbia	40	21.1	3.34 (158)	.07	.20	.15	.06
		200	4.8	3.93 (819)	.09	.17	.08	.05
7.0	None	-	25.7	0.90 (35)	.02	.09	.18	.07
		†	26.8	2.65 (99)	.12	.29	.16	.09
	Decatur	40	28.8	1.75 (61)	.10	.25	.14	.08
		200	30.4	4.41 (145)	.27	.45	.25	.11
	Tuscumbia	40	22.2	2.22 (100)	.07	.20	.13	.08
		200	4.5	2.61 (580)	.09	.16	.05	.02

*Values in parentheses represent average ppm of Zn.
†Inorganic salts equivalent in Zn, Dc, Cu, Pb, and Ni content to 40 grams of Tuscumbia sewage sludge.

B. RESPONSE OF CORN TO Zn AND Cr IN MUNICIPAL WASTES APPLIED TO SOIL

This experiment was conducted to determine if Zn and Cr in several municipal waste products becomes available to plants after soil incubation and successive cropping (13).

A greenhouse pot experiment was conducted using Hartsells fine sandy loam from northern Alabama. This soil was limed to pH 5.5 and the following supplemental nutrients were mixed with the soil in each pot containing 3 kg of soil: 600 mg of N as NH_4NO_3, 300 mg of P as concentrated superphosphate, 200 mg of K as K_2SO_4, and 20 mg of Mn as $MnSO_4$. The amounts of nutrients added in sewage sludge or compost were in addition to the above nutrients.

The cropping sequence was: Crop 1--planted immediately after waste application and grown for 7 weeks; Crop 2--planted after moist soil incubation for 21 weeks at 25C and grown for 7 weeks; Crop 3--similar incubation for 36 weeks and grown for 7 weeks. The soils treated with $ZnSO_4$ and $Na_2Cr_2O_7$ were discarded after Crop 2. Before Crops 2 and 3 were planted the following nutrients were mixed with the soil per pot: 200 mg of N as NH_4NO_3, 200 mg of P and 252 mg of K as KH_2PO_4. An additional 400 mg of N/pot as a solution of NH_4NO_3 was applied during the growth period.

The three waste products were applied at rates of 15, 75, and 300 grams/3 kg of soil (11, 56, and 224 metric tons/ha), supplying 7 to 1,400 ppm of Zn and 1 to 1,360 ppm of Cr (Table 28). Fine $ZnSO_4$ and $Na_2Cr_2O_7$ were mixed with the soil alone and together in separate series to provide 12, 60, 240, and 1,400 ppm of Zn and 1, 5, 20, 80, and 320 ppm of Cr, respectively.

After each harvest the soil in each pot was core-sampled, air-dried, and screened (20 mesh). The soil was extracted by 0.5 N HCl and by DTPA. Two samples of air-dried sewage sludge obtained from municipal plants equipped with secondary treatment facilities were used. Sludge A (containing 1.36% Cr) from Sheffield, Alabama, was contaminated by apparent leakage of industrial waste into a municipal sewer system; Sludge B (containing 0.05% Cr) was obtained from the Tuscumbia plant. The garbage compost sample was obtained from the Johnson City, Tennessee, compost plant. The composted product contained about 20% sewage sludge.

Five plants of corn (cv. 'Funk's 4455') were grown per pot for 7 weeks during which deionized water was added to the soil daily to 0.3 atm moisture tension. Supplemental lighting was provided to maintain a day length of 16 hours. After harvest the forage in triplicates of each treatment was dried, weighed, and analyzed for Zn and Cr by atomic absorption spectroscopy using the standard techniques.

TABLE 28. FORAGE YIELDS AND Zn AND Cr CONCENTRATIONS IN THREE CORN CROPS AS AFFECTED BY SOIL APPLICATION OF MUNICIPAL WASTES.

Treatment	Rate		Yield			Zn in tissue			Cr in tissue		
			Crop			Crop			Crop		
	Zn	Cr	1	2	3	1	2	3	1	2	3
	- - - ppm - - -		- grams/pot -			- - - - ppm - - - -			- - - - ppm - - - -		
--	0	0	31	48	30	14	18	16	1.3	2.1	2.0
Sludge A	70	68	33	50	34	196	121	163	1.2	1.7	2.3
	350	340	35	45	32	325	206	249	1.2	3.0	5.4
	1,400	1,360	30	50	31	508	428	340	1.4	1.5	2.0
Sludge B	11	3	32	49	27	60	66	62	2.3	2.3	3.0
	53	13	34	48	34	120	114	140	1.4	3.5	1.3
	210	50	19	51	36	313	153	186	1.4	1.4	0.6
Compost	6	3	34	51	31	31	32	34	1.1	1.9	2.8
	30	13	36	47	41	50	43	44	1.1	1.6	1.8
	120	50	37	46	40	92	58	56	2.0	1.2	0.7
C.V., %			6	6	11	14	23	16	25	35	43

Yields from the three crops were not greatly affected by application of Sludge A, even though this product contained relatively high Zn and Cr concentrations (see Appendix). A decrease in yield was noted at the highest application rate of Sludge B in Crop 1 only. This apparent toxicity may have been caused by some unidentified compounds found in used motor oils present in this product. Yields were higher with the two highest compost rates in Crops 1 and 3 only.

Concentration of Zn in plant tissue increased with application rate of all waste products in all crops. Concentrations were higher from soils treated with Sludge A, followed by Sludge B and compost, the same order as the amounts of Zn contained in these products. Thus, Zn contained in these waste products was available to plants for a long period in the soil. Sludge A contained a high level of Zn (1.4%), but no toxicities were noted even at the highest application rates.

Concentrations of Zn in plant tops generally decreased from Crop 1 to Crop 3 with the two high rates of comparable treatments, indicating that the Zn in the wastes was becoming less available with time. Lower Zn concentrations in Crop 2 could have been due to dilution with the higher yield levels in this crop. Crop removals accounted for less than 5% of the Zn contained in the wastes.

Concentrations of Cr in all three corn crops were not affected by waste applications. The high Cr level in Sludge A resulted in a very high application rate (1,360 ppm), yet neither plant growth nor Cr uptake was affected by applications of this product. Thus, availability to the plant of Cr contained in these wastes applied to soil is very low.

Forage yields (Table 29) decreased with $ZnSO_4$ applications of 240 and 1,400 ppm of Zn in Crops 1 and 2 and with $Na_2Cr_2O_7$ applications of 20, 80, and 320 ppm of Cr in Crop 1. Little growth resulted at the 1,400-ppm Zn and 320-ppm Cr rates. Including $Na_2Cr_2O_7$ with $ZnSO_4$ in a separate treatment (data not shown) did not have any more deleterious effect on plant growth at any Zn rate. Toxicity to corn of either Zn or Cr was not as pronounced in Crop 2, suggesting a reduction in the plant availability of each inorganic source with time.

Concentrations of Zn in corn tissue increased with $ZnSO_4$ application rate and were much higher than those in corn grown on waste-treated soils at comparable Zn rates. Zinc concentrations in corn tissue decreased from Crop 1 to Crop 2, thus reflecting a rapid fixation of the applied $ZnSO_4$ in less-available forms.

Chromium concentrations in plant tops were increased by the two highest $Na_2Cr_2O_7$ rates in Crop 1 and by the highest rate in Crop 2. Little plant growth resulted at these Cr rates. Concentrations of Cr in the growth-retarded corn were 5 ppm in Crop 1 and 9 ppm in Crop 2. The narrow range in Cr concentrations in plant tops between normal

TABLE 29. FORAGE YIELDS AND Zn AND Cr CONCENTRATIONS IN TWO CORN CROPS AS AFFECTED BY SOIL APPLICATION OF $ZnSO_4$ AND $Na_2Cr_2O_7$.

Treatment	Rate		Yield		Zn in tissue		Cr in tissue	
			Crop		Crop		Crop	
	Zn	Cr	1	2	1	2	1	2
	- - - ppm - -		grams/pot		- - ppm - -		- - ppm - -	
—	0	0	31	48	14	18	1.3	2.1
$ZnSO_4$	12	--	33	49	104	60	1.4	1.1
	60	--	30	45	1,640	242	1.1	2.0
	240	--	17	38	3,067	892	2.1	2.3
	1,400	--	1	*	10,178	*	3.5	*
$Na_2Cr_2O_7$	--	1	32	49	13	17	1.5	1.4
	--	5	32	50	13	17	1.5	1.9
	--	20	27	50	14	16	2.3	1.9
	--	80	4	55	35	15	5.0	2.2
	--	320	1	6	19	28	16.1	9.3
C.V., %			14	13	21	15	20	44

*Plants did not emerge or died shortly after emergence.

and retarded growth suggests that Cr is toxic to plant roots but that translocation of Cr to plant tops is limited.

Soil pH increased with application rate of all three wastes, especially with compost applications (Table 30). This is related to relatively high contents of Ca and Mg. A decrease in soil pH was noted with time in all treatments, which could be related to the application of fertilizers to the soil prior to each crop. Soil pH was not affected by applied $ZnSO_4$ or $Na_2Cr_2O_7$.

Levels of 0.5 N HCl-extractable Zn and Cr in the soil after each crop increased with application rate of each product. The order was Sludge A > Sludge B > compost, the same order as their content of these heavy metals. Extractable Zn and Cr did not change appreciably with time, except that increased levels of both elements were noted at the two highest rates of Sludge A. The percentage recovery of Zn and Cr applied with these wastes by this extractant varied considerably with time and application rate. Maximum recovery of Zn and Cr was about 60% at the highest waste application rate.

The level of 0.5 N HCl-extractable Zn increased with $ZnSO_4$ application rate from 5 to 1,305 ppm after Crop 1 and from 7 to 640 ppm after Crop 2. Extractable Cr also increased with $Na_2Cr_2O_7$ application rate but the percentage recovery of applied Cr was lower than that of Zn. Lower levels of extractable Zn and Cr after Crop 2 indicate fixation in the soil with time.

The level of DTPA-extractable Zn also increased with rate of applied Zn (data not shown), but in each instance was lower than with 0.5 N HCl. The higher recovery by 0.5 N HCl probably was due to degradation of some of the organic matter in the wastes as well as dissolution of some soil Zn by the acid extractant. Also, DTPA may not have been able to compete with some organic ligands for the Zn applied with these products. The level of Cr in the DTPA extracts was too low to detect by the method used.

TABLE 30. SOIL pH AND 0.5 N HCl-EXTRACTABLE Zn AND Cr AFTER EACH OF THREE CORN CROPS GROWN ON SOIL TREATED WITH MUNICIPAL WASTES, $ZnSO_4$, or $Na_2Cr_2O_7$.

Treatment	Rate		Soil pH after Crop			Extractable Zn after Crop			Extractable Cr after Crop		
	Zn	Cr	1	2	3	1	2	3	1	2	3
	- - - ppm - -					- - - - ppm - - - -			- - - - - ppm - - - - -		
--	0	0	4.9	4.8	4.5	0	1	1	1	1	1
Sludge A	70	68	5.5	5.1	4.7	71	38	49	60	44	19
	350	340	5.8	5.7	5.5	172	196	211	81	149	139
	1,400	1,360	6.2	6.3	6.0	635	785	855	430	455	607
Sludge B	11	3	5.2	4.9	4.6	7	8	9	1	3	2
	53	13	5.5	5.3	4.8	19	31	29	2	4	3
	210	50	5.9	6.0	5.7	116	126	124	16	17	7
Compost	6	3	5.4	5.1	4.7	4	4	4	1	1	1
	30	13	5.6	5.7	5.2	12	14	12	1	2	1
	120	50	6.6	6.9	6.5	40	62	51	1	3	1
$ZnSO_4$	12	-	4.8	4.8	-	5	7	-	1	1	-
	60	-	4.8	4.7	-	39	34	-	1	1	-
	240	-	4.6	4.7	-	152	119	-	1	1	-
	1,400	-	4.7	4.8	-	1,305	640	-	1	1	-
$Na_2Cr_2O_7$	-	1	4.7	4.8	-	1	2	-	2	1	-
	-	5	4.8	4.9	-	2	2	-	3	1	-
	-	20	4.7	4.9	-	2	1	-	3	4	-
	-	80	4.8	5.1	-	4	1	-	14	11	-
	-	320	4.8	5.3	-	4	1	-	92	71	-
C.V., %			2	1	2	20	16	21	17	16	21

C. RELATIONSHIP OF Zn AND Cd SUPPLY TO UPTAKE BY FESCUE

It has been claimed that sewage sludges containing Zn and Cd in ratios less than 100 to 1 should not be applied to agricultural land (2, 3). This rule is based on the premise that excess Zn prevents toxic accumulations of Cd by first causing plant injury. This experiment was conducted to determine whether varying the ratio of Zn to Cd in the soil influences their mutual uptake.

Lakeland sand (pH 5.2) was fertilized preplant with 400 mg of N as NH_4NO_3, 200 mg of P as concentrated superphosphate, and 200 mg of K as K_2SO_4 (2 kg of soil per pot). Chlorides of Zn and Cd were applied in factorial combination at the rates shown in Table 31. Extra pots were included to compare sewage sludges from Decatur and Florence, Alabama, each applied at a rate of 200 grams of dry material per pot. Another treatment contained Florence sewage sludge plus $CdCl_2$ to equal the Cd content of the Decatur sludge (Table 32). Tall fescue (Festuca arundinacea Schreb., cv. 'Kentucky 31') was planted and clippings from triplicates of each treatment were harvested at monthly intervals over a 4-month period. An additional 200 mg of N, 100 mg of K, and 250 mg of a micronutrient mix, minus Zn, was applied as a solution to the soil surface of all pots after the third harvest. The oven-dried clippings from each harvest were weighed, ground, and analyzed for Zn and Cd content. Clippings from sludge-treated pots were also analyzed for Cu, Ni, and Pb.

Dry matter production of fescue decreased with rate of Zn application (Table 31); however, only the 100-mg rate of Cd resulted in decreased yields. Yields were much higher in pots of soil amended with Decatur and Florence sewage sludges (Table 32). Since all pots received seemingly adequate amounts of N, P, K, and micronutrients, as well as water, there is no obvious explanation for the enhanced growth with sewage sludge applications.

Uptake of Zn increased with 100 mg of Zn but decreased in some cases with 500 mg as a result of toxicity to the plant preventing additional uptake (Table 31). Level of Cd applied to the soil did not affect plant Zn concentration consistently. Increased Cd rate depressed Zn concentration in the fescue only at the 100-mg Zn rate.

Uptake and concentration of Cd increased with rate of applied Cd but concentrations were unaffected by Zn application. These results suggest that Cd concentrations greater than about 100 ppm in fescue may be toxic to plant growth. However, rather high concentrations can occur in fescue without visual indication of toxicity.

The greater yields from the sludge-amended pots occurred even though rates of Zn applied in the sludge were high (Table 32). Apparently plant availability of Zn in the sewage sludges was much less than

TABLE 31. TOTAL DRY MATTER YIELD AND UPTAKE OF Zn AND Cd IN FOUR CUTTINGS OF FESCUE.

Zn rate, mg/pot	Cd rate, mg/pot	Dry matter, grams/pot	Uptake, µg/pot		Concentration, ppm	
			Zn	Cd	Zn	Cd
0	0	6.4	183	2	27	0.4
	4	6.6	182	144	26	25
	20	6.1	181	521	31	81
	100	1.4	48	437	35	229
100	0	4.4	3392	16	747	3.4
	4	3.7	3122	110	829	26
	20	3.7	2277	399	511	74
	100	1.8	790	832	414	423
500	0	1.2	2079	5	1485	3.5
	4	1.2	3089	19	2002	25
	20	1.0	3526	81	2240	99
	100	0.6	1821	201	2194	412

TABLE 32. TOTAL DRY MATTER YIELD AND HEAVY METAL UPTAKE IN FOUR CUTTINGS OF FESCUE FROM SOIL AMENDED WITH SEWAGE SLUDGE.

Sewage sludge	Amount element supplied in sludge, mg/pot		Dry matter, grams/pot	Uptake, µg/pot					Concentration, ppm	
	Zn	Cd		Zn	Cd	Cu	Ni	Pb	Zn	Cd
Decatur	360	13	13.2	1708	39	191	94	49	129	3.0
Florence	360	2	11.0	4690	18	217	297	36	426	1.6
Florence	360	2 (+11)*	13.2	4594	78	287	359	56	348	5.9

*Additional Cd added to soil as $CdCl_2$ to equalize amount supplied in Decatur sludge.

that of $ZnCl_2$. Also, the availability of Zn in the Decatur sludge was less than in the Florence sludge. Likewise, Cd availability was less from the organic wastes than from $CdCl_2$. Equalizing the Cd content in Florence sludge to that of Decatur sludge with $CdCl_2$ resulted in higher concentrations and uptake of Cd.

Plant uptake of Cu was somewhat higher from soil treated with Florence than with Decatur sludge, while Pb uptake was similar. Although Ni content of Florence sludge was less than twice the content of the Decatur sludge, plant uptake was more than three times as great. Based on Zn, Cu, and Ni uptake, it would appear that these elements are present in a more available form in the Florence than in the Decatur sludge. Differences in plant availability of heavy metals in these sludges possibly could be related to the method of waste treatment; Florence uses an activated sludge process, while Decatur uses the anaerobically digested sludge process.

SECTION VII

SOIL MOBILITY STUDIES

A. NITROGEN EFFECTS ON MOBILITY AND PLANT UPTAKE OF HEAVY METALS IN SEWAGE SLUDGE APPLIED TO SOIL COLUMNS

There is current concern that land disposal of large quantities of sewage sludge on some soils may result in heavy metal contamination of ground water. However, there is little information in the literature regarding mobility of metals such as Cd, Cr, Ni, and Pb. The purpose of these experiments was to determine the possible effect of N fertilizer on the movement of several heavy metals in soil under leaching conditions (6).

Leaching columns consisting of 60-cm sections of 15-cm plastic well casings were packed from bottom to top with 800 grams of coarse quartz sand, 1,200 grams of fine quartz sand, and 10 kg of a mixture consisting of eight parts Ennis fine sandy loam (pH 5.4) and two parts fine quartz sand. The resulting systems contained about 40% pore space. This soil contained 1.2% organic matter, 184 ppm of Bray No. 2 extractable P, and had a cation exchange capacity (CEC) by ammonium ion displacement of 5.6 meq/100 grams. An additional 5 kg of the same soil-sand mixture, containing the following nutrients, was added to the columns: P--500 mg as concentrated superphosphate, and K--300 mg as K_2SO_4. A 0.42-cm mesh plastic screen was used to separate the fertilized soil from the nonfertilized soil. Nitrogen as granular urea and sulfur-coated urea (SCU) containing 36.7% N and 21% S was also mixed with the top 5 kg of soil in some columns at a rate of 750 mg (Table 33). Elemental S plus granular urea was applied to other columns in a similar manner to simulate rates of N and S from the SCU. Other treatments included Tuscumbia sewage sludge mixed with the top 5 kg of soil to approximate an application rate of 224 metric tons/ha of dry matter and heavy metals applied as inorganic salts at rates equivalent to those supplied in the sewage sludge (Zn--840 mg; Pb--640 mg; Cr--215 mg; Ni--117 mg; and Cd--19 mg).

Three replicate columns of each treatment were planted to fescue and maintained in the greenhouse. Enough deionized water was added to all columns after planting and during the experiment to maintain good growth. All columns were leached with the equivalent of 12 cm of deionized water at 4, 8, and 12 weeks after planting. A vacuum system exerting a suction of about 0.2 atm at the bottom of each column was used to expedite leaching. Grass clippings were harvested after 6, 10, and 14 weeks, dried at 70C, and weighed. After the last harvest, each soil column was carefully removed intact from the casing and sampled at 1-cm increments below the screen which originally separated the treated from the nontreated soil. Samples of soil were extracted with 0.5 N HCl. Leachate, clippings, and soil

TABLE 33. MOBILITY OF SEVERAL HEAVY METALS IN COLUMNS OF ENNIS SOIL AS AFFECTED BY N AND HEAVY METAL SOURCES.

N source	Heavy metal source*	Depth, cm†	0.5 N HCl-extractable heavy metals, ppm in soil				
			Cd	Cr	Ni	Pb	Zn
--	--	-	0.2	0.4	1.2	2.0	4
--	Inorganic	0-1	1.0	1.1	5.5	7.9	35
		1-2	0.4	0.8	2.8	4.2	15
		2-3	0.3	0.7	1.9	2.6	10
Urea	--	0.1	0.2	0.5	1.3	2.1	5
		1-2	0.2	0.5	1.3	2.0	5
		2-3	0.2	0.6	1.3	2.1	5
Urea	Inorganic	0-1	1.1	0.9	5.9	8.3	29
		1-2	0.3	0.6	2.4	2.3	10
		2-3	0.3	0.6	2.0	2.6	8
Urea	Inorganic + S	0-1	1.1	1.1	6.3	10.9	40
		1-2	0.5	0.7	3.0	2.0	19
		2-3	0.3	0.7	1.9	2.1	10
Urea	Sludge	0-1	0.4	0.5	1.2	6.2	12
		1-2	0.2	0.4	1.1	1.8	4
		2-3	0.2	0.4	1.2	2.1	4
SCU	--	0-1	0.2	0.6	1.2	2.7	5
		1-2	0.2	0.7	1.2	2.4	5
		2-3	0.2	0.6	1.3	2.4	5
SCU	Inorganic	0-1	1.0	1.1	6.0	8.1	37
		1-2	0.3	0.7	2.2	2.4	12
		2-3	0.3	0.8	1.8	2.4	11
		$S_{\bar{x}}$	0.7	0.5	2.1	4.9	14

*Inorganic sources of Cd, Cr. Ni, Pb, and Zn equivalent to amounts supplied by sludge.
†Depth in soil below zone of treated soil.

extracts were analyzed for Zn, Cd, Cr, Ni, and Pb by atomic absorption or flameless atomization when elemental concentration was below the detection limit of the flame.

A second series of leaching columns was prepared using a similar technique but with a 1:1 mixture of quartz sand and Decatur silt loam (pH 5.2). The sand was added to the soil to accelerate the rate of leaching. The Decatur silt loam contained 1.8% organic matter, 168 ppm of Bray No. 2 extractable P, and had a CEC of 9.7 meq/100 grams. Nutrients and other amendments were mixed with the upper 5 kg of sand-soil mixture. Treatments in duplicate soil columns are shown in Table 34. One replicate of each treatment was left fallow and the second planted to 'Kentucky 31' fescue. Leachate was collected as in the previous experiment at 4, 8, and 12 weeks after planting and the cropped columns were clipped after 6, 10, and 14 weeks. The columns were sectioned and the soil extracted as previously described.

Despite the adding of quartz sand to the Ennis soil, percolation of water through the soil columns was extremely slow, even when vacuum was applied. This was probably a result of soil compaction which may have been related to the high percentage of silt in the soil. The volume of leachate recovered from the columns after adding 2,000 mg ranged from 200 to 1,000 ml. Analyses of the leachate showed that the concentrations of Zn, Cd, Cr, Ni, and Pb were not increased by soil application of sewage sludge or inorganic salts, indicating that none of the applied heavy metals leached entirely through the non-treated portion of the soil column (45 cm).

Data in Table 33 further indicate that little downward movement of the heavy metals occurred as a result of the three leachings. Although differences were small, mobility of heavy metals applied in the sludge appeared to be less than that of the inorganic sources. In general, Cd and Pb were less mobile than the others. Despite the higher stability constant of manure and other fecal complexes than of soil organic matter complexes, it appears that metal complexes formed in municipal sewage sludges are not readily leached from the soil, at least over short periods.

Heavy metal movement was not enhanced by application of N fertilizers. Any anion effects on cation movement may have been negated by the poor soil structure which prevented free water flow. Further, denitrification of the applied N may have occurred as a result of waterlogged conditions that prevailed for several hours after each leaching.

There was no indication that urea or SCU influenced heavy metal uptake other than as a result of increased growth in response to N (Table 34). A slight yield increase as well as uptake of Zn, Cd, Pb, and Ni was obtained in the presence of elemental S with urea plus the heavy metals. This increase may have been due to a slight localized

TABLE 34. DRY WEIGHT AND CUMULATIVE UPTAKE OF SEVERAL HEAVY METALS IN THREE CLIPPINGS OF FESCUE.

Treatment	Dry weight, grams/column	Cumulative uptake, mg/column				
		Zn	Cd	Cr	Pb	Ni
No N	2.2	0.08	< .01	< .01	< .01	.01
No N + heavy metals	5.5	1.13	.07	.02	.01	.18
Urea	13.4	0.32	.01	.03	.01	.09
Urea + heavy metals	3.8	4.77	.12	.05	.03	.52
Urea + heavy metals + S	15.5	5.47	.15	.04	.04	.73
Urea + sewage sludge	6.8	0.75	.01	.01	.01	.04
SCU	9.5	0.23	.01	.01	.01	.05
SCU + heavy metals	12.7	4.30	.12	.05	.03	.36
$S_{\bar{x}}$	0.7	0.32	.03	.01	.006	.10

acidification in the soil upon oxidation of S, although gross pH measurements at the end of the study did not show a decrease. Apparently sludge applied with urea was either toxic to the grass or it immobilized most of the N, based on the low dry matter production. Results of an earlier study (7) indicated that high rates of sludge were toxic to string beans. This was attributed to excessive Zn uptake. Despite the high Cr content of the sludge, uptake was negligible, as was observed previously (13). Grass clipping yields increased slightly with applied heavy metals despite the much greater uptake of Zn, Cd, and Ni.

Although the percolation rate of water through the columns of Decatur soil-sand mixture was much greater than that through the Ennis soil-sand mixture, the leachate contained less than 20 parts per billion (ppb) of Pb and Ni, and concentrations of Zn, Cr, and Cd were non-detectable. Leachates from cropped and fallow columns were comparable in heavy metal concentration, indicating that roots had little effect on metal movement. In general, concentrations of Cd, Cr, Ni, and Zn were lower in the Decatur than in the Ennis soil (Tables 33 and 35).

Movement of most heavy metals was generally greater in the Decatur soil when the metals were applied as inorganic salts (Table 35). Mobility of heavy metals contained in sludge was negligible. Movement of metals in cropped and fallow soils was similar, although concentrations in the cropped soil tended to be consistently lower, possibly due to plant uptake.

Dry weight and cumulative heavy metal uptake of fescue were similar to that in the previous experiment (Table 36). Application of sludge alone resulted in poorer growth than application of sludge with urea. Since the poor growth apparently was not related to Zn, Cd, Cr, Ni, or Pb toxicity, it is possible that the combination of Mn present in the sludge (253 ppm) and the excessive moisture in the soil following leaching could have resulted in Mn toxicity, although Mn concentrations in the fescue were not determined.

TABLE 35. MOBILITY OF SEVERAL HEAVY METALS IN COLUMNS OF DECATUR SOIL AS AFFECTED BY N AND HEAVY METAL SOURCES.

N source	Heavy metal source*	Depth, cm†	0.5 N HCl-extractable heavy metals, ppm in soil				
			Cd	Cr	Ni	Pb	Zn
Urea	--	0-.5	.01	.05	.20	2.0	1.2
		.5-1	.04	.04	.30	2.3	1.6
		1-2	.03	.04	.20	2.1	1.4
		2-3	.02	.05	.20	2.1	1.4
Urea	Inorganic	0-.5	1.0	.60	5.1	8.5	29
		.5-1	1.2	.40	6.4	3.0	31
		1-2	1.4	.10	6.9	2.0	35
		2-3	1.8	.10	8.6	2.3	45
Urea	Sludge	0-.5	.30	.10	.30	11.5	11.0
		.5-1	.02	.05	.20	2.3	1.7
		1-2	.01	.05	.10	2.0	1.7
		2-3	.02	.05	.10	2.5	1.7
No N	Sludge	0-.5	.80	.70	.50	35.0	10.0
		.5-1	.10	.10	.20	8.8	7.3
		1-2	.02	.05	.20	2.3	1.9
		2-3	.02	.05	.20	2.0	1.7

*Inorganic sources of Cd, Cr, Ni, Pb, and Zn equivalent to amounts supplied by sludge.
†Depth in soil below zone of treated soil.

TABLE 36. DRY WEIGHT AND CUMULATIVE UPTAKE OF SEVERAL HEAVY METALS IN THREE CLIPPINGS OF FESCUE.

Treatment	Dry weight, grams/column	Cumulative uptake, mg/column				
		Zn	Cd	Cr	Pb	Ni
Urea	15.5	0.40	.01	.04	.02	.06
Urea + heavy metals	14.5	4.36	.20	.03	.09	.91
Urea + sewage sludge	4.4	0.39	.01	< .01	.01	.02
Sewage sludge	0.5	0.09	< .01	.01	< .01	.04

B. MOVEMENT OF HEAVY METALS IN SOILS FROM MUNICIPAL WASTES AND INORGANIC SOURCES

The previous experiment indicated that very little heavy metal movement occurred in soils leached periodically in the greenhouse for 3 months. The present experiments were initiated to determine the extent of metal movement in soil under natural conditions of precipitation and temperature fluctuation over an extended period.

Ennis fine sandy loam (pH 5.4) was placed in bins of the TVA rhizotron-lysimeter facility (16) in the spring of 1973. Unreplicated treatments consisted of (i) check, (ii) orthophosphate (250 kg of P/ha), (iii) orthophosphate plus inorganic heavy metals, (iv) polyphosphate (250 kg of P/ha), (v) polyphosphate plus inorganic heavy metals, (vi) Tuscumbia sewage sludge (224 metric tons/ha), (vii) sludge plus orthophosphate, (viii) sludge plus polyphosphate, (ix) Johnson City compost (224 metric tons/ha), and (x) compost plus orthophosphate. All amendments were incorporated into the upper 15cm of soil. Sweet corn was planted in each bin followed after harvest by a crop of string beans. All treatments except the inorganic heavy metals were reapplied in April 1974 and the bins cropped as before. Leachate was collected throughout the experiment for heavy metal assay. After the beans were harvested in mid-October 1974, soil borings were taken from all bins to a depth of 60 cm. Samples of soil were extracted with 0.5 N HCl to estimate downward movement.

In general, movement of Zn, Cu, Cd, Cr, Ni, and Pb was similar from all heavy metal sources and with ortho- or polyphosphate fertilizers. Apparently the polyphosphate had no effect on mobilization of the metals by solubilization or sequestration. Approximately 80% of the applied heavy metals remained in the top 15-cm (data not shown). Levels of Zn, Cu, and Cd slightly above the check values were detected to a depth of 120 cm in the sludge-treated soils. Analyses of the leachates from these and other bins confirmed that the metals had not moved through the entire soil profile, however.

Due to the slow rate and irregular percolation of water through the soil in this experiment, it was impossible to evaluate conclusively the mobility in soil of heavy metals from these organic and inorganic sources. Therefore, the Ennis soil was replaced with Decatur silty clay. Treatments included (i) check, (ii) Tuscumbia sewage sludge (224 metric tons/ha), and (iii) Florence sewage sludge (224 metric tons/ha). The sludge materials were incorporated into the upper 15-cm layer of soil as before. Duplicate bins were used for each of these treatments. As in the previous experiment, the cropping sequence was sweet corn followed by string beans. In addition to collecting leachate from below each bin and sampling soil at varying depths, porous ceramic tubes were installed horizontally in the soil at depths of 15, 45, 75, and 120 cm for extraction of soil solution.

Heavy metal concentrations in soil solution and leachate were monitored from early spring of 1974 until mid-October of 1975 when soil borings were taken.

Despite the superior drainage characteristics of the Decatur compared with the Ennis soil, movement of heavy metals from the zone of application was negligible. (Estimates of percolates expressed as percentages of total rainfall plus supplemental irrigation were 40% for the Ennis and 60% for the Decatur soil.) Acid-extractable levels of heavy metals above check soil values were not observed beyond a depth of 15 cm (data not shown). Zinc was the only heavy metal detected in soil solution even from probes situated in the treated zone (15 cm). Although concentrations of Zn were very variable, values at 15 cm averaged about 0.4, 0.8, and 2.7 ppm in the check, Tuscumbia sludge-, and Florence sludge-treated soil, respectively. Soil solution concentrations of Zn did not exceed check soil levels at greater depths (45, 75, and 120 cm).

SECTION VIII

REFERENCES

1. Carlson, C. W., and J. D. Menzies. Utilization of urban wastes in crop production. BioSci. 21:561-564. June 1971.

2. Chaney, R. L. Crop and food chain effects of toxic elements in sludges and effluents. In Recycling Municipal Sludges and Effluents on Land. Proc. Joint Conf. Natl. Assoc. State Univ. and Land-Grant Colleges, Washington DC. pp. 129-141. July 1973.

3. Chaney, R. L. Land application of sewage sludge: Benefits and problems. In Proc. 1973 Lime and Fertilizer Conf., Delaware-Maryland Plant Food Assoc. 5:15-23. 1973.

4. Chaney, R. L. Recommendations for management of potentially toxic elements in agricultural wastes. In Factors Involved in Land Application of Agricultural and Municipal Wastes, ARS-USDA. pp. 97-120. 1974.

5. Giordano, P. M., and D. A. Mays. Yield and heavy metal content of several vegetable species grown in soil amended with sewage sludge. In Biological Implications of Metals in the Environment, 15th Annual Hanford Life Science Symposium. 1976. (In press).

6. Giordano, P. M., and J. J. Mortvedt. Nitrogen effects on mobility and plant uptake of heavy metals in sewage sludge applied to soil columns. J. Environ. Qual. 5:165-168. 1976.

7. Giordano, P. M., J. J. Mortvedt, and D. A. Mays. Effect of municipal wastes on crop yields and uptake of heavy metals. J. Environ. Qual. 4:394-399. 1975.

8. Hortenstine, C. C., and D. F. Rothwell. Use of municipal compost in reclamation of phosphate-mining sand tailings. J. Environ. Qual 1:415-418. 1972.

9. Kochtitzky, O. W., W. K. Seamon, and J. S. Wiley. Municipal composting research at Johnson City, Tennessee. Compost Sci. 9:5-16. 1969.

10. Lindsay, W. L., and W. A. Norvell. Development of a DTPA micronutrient soil test. In Agronomy Abstracts. p. 84. 1969.

11. Mays, D. A., G. L. Terman, and J. C. Duggan. Municipal compost: Effects on crop yields and soil properties. J. Environ. Qual. 2:89-92. 1973.

12. McIntyre, D. R., and W. J. Silver. Trace element uptake by field-grown food plants fertilized with waste water sewage sludge. In Agronomy Abstracts. p. 29. 1975.

13. Mortvedt, J. J., and P. M. Giordano. Response of corn to zinc and chromium in municipal wastes applied to soil. J. Environ. Qual. 4:170-174. 1975.

14. Purvis, D., and E. J. MacKenzie. Effect of applications of municipal compost on uptake of Cu, Zn, and B by garden vegetables. Plant Soil. 39:361-371. 1973.

15. Simon, P. W., R. L. Chaney, and E. Epstein. Heavy metal contents of selected vegetable crops grown on sewage sludge and composted sewage sludge-amended soil at two pH's. In Agronomy Abstracts. p. 39. 1974.

16. Soileau, J. M., D. A. Mays, F. E. Khasawneh, and V. J. Kilmer. The rhizotron-lysimeter research facility at TVA, Muscle Shoals, Alabama. Agron. J. 66:828-832. 1974.

17. Terman, G. L., and D. A. Mays. Utilization of municipal solid waste compost: Research results at Muscle Shoals, Alabama. Compost Sci. 14:18-21. 1973.

18. Terman, G. L., J. M. Soileau, and S. E. Allen. Municipal waste compost: Effects on crop yields and nutrient content in greenhouse pot experiments. J. Environ. Qual. 2:84-89. 1973.

19. Van Loon, J. C. Mercury contamination of vegetation due to the application of sewage sludge as a fertilizer. Environ. Letters 6:211-218. 1974.

SECTION IX

PUBLICATIONS

The following publications have resulted from work supported by this project:

1. Terman, G. L., and D. A. Mays. 1973. Utilization of municipal solid waste compost: Research results at Muscle Shoals, Alabama. Compost Sci. 14:18-21.

2. Mays, D. A., G. L. Terman, and J. C. Duggan. 1973. Municipal compost: Effects on crop yields and soil properties. J. Environ. Qual. 2:89-92.

3. Terman, G. L., J. M. Soileau, and S. E. Allen. 1973. Municipal waste compost: Effects on crop yields and nutrient content in greenhouse pot experiments. J. Environ. Qual. 2:84-89.

4. Mortvedt, J. J., and P. M. Giordano. 1975. Response of corn to zinc and chromium in municipal wastes applied to soil. J. Environ. Qual 4:170-174.

5. Giordano, P. M., J. J. Mortvedt, and D. A. Mays. 1975. Effect of municipal wastes on crop yields and uptake of heavy metals. J. Environ. Qual. 4:394-399.

6. Giordano, P. M., and D. A. Mays. 1976. Yield and heavy metal content of several vegetable species grown in soil amended with sewage sludge. In Biological Implications of Metals in the Environment, 15th Annual Hanford Life Science Symposium. (In press).

7. Giordano, P. M., and J. J. Mortvedt. 1976. Nitrogen effects on mobility and plant uptake of heavy metals in sewage sludge applied to soil columns. J. Environ. Qual. 5:165-168.

SECTION X

APPENDIX

PARTIAL CHEMICAL COMPOSITION OF DIGESTED MUNICIPAL WASTE PRODUCTS

Element*	Johnson City Compost	Tuscumbia Sewage	Decatur Sewage	Florence Sewage	Sheffield Sewage
	- - - - - - - - - - - - % in air-dry material - - - - - - - - - - - -				
N	1.4	2.1	2.3	3.6	1.8
P	0.4	1.3	1.6	2.8	5.3
K	0.9	0.1	0.1	0.1	0.1
Ca	3.6	1.7	2.5	0.3	3.0
Mg	0.4	0.1	0.1	0.1	0.2
	- - - - - - - - - - - - ppm in air-dry material - - - - - - - - - - - -				
Cu	340	520	730	900	230
Mn	400	200	400	800	180
Fe	13,000	15,000	17,000	2,400	11,300
B	50	20	--	--	30
Zn	1,600	1,800	1,800	1,800	15,700
Cd	10	40	50	10	60
Cr	500	400	350	2,100	13,900
Pb	450	1,600	530	100	300
Ni	300	40	20	150	30
Co	--	9	10	7	7
pH	7.2	6.1	6.6	4.4	6.3

*Nitrogen determination was according to a standard Kjeldahl procedure, P by the vanadomolybdate method, and the other elements by conventional atomic absorption or flame emission spectroscopy.